EEPSEA
2015-RR11

A Cost-Benefit Analysis of Dike Heightening in the Mekong Delta

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Published by WorldFish (ICLARM) – Economy and Environment Program for Southeast Asia (EEPSEA)
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ISBN: 978-971-9994-92-3

Front cover photo: Tong Yen Dan

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May, 2015

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ACKNOWLEDGMENTS

I would like to express my sincere gratitude to the following organizations and individuals for their invaluable support, guidance, assistance, and encouragement:

To the Economy and Environment Program for Southeast Asia (EEPSEA) for awarding me the Doctoral Dissertation Research Grant to do this research;

To the Australian Development Scholarship (ADS) for sponsoring my PhD study;

To Dr. Herminia Francisco for her helpful comments, support, and encouragement;

To Dr. Benoit Laplante, my project advisor, for his constructive comments and suggestions in shaping the structure of the study and data analyses;

To Dr. David James, my project advisor, for his reviews and suggestions on my report;

To Professor Harry Clarke, my PhD. supervisor, who has been a constant source of inspiration and encouragement, for his hearty help and invaluable comments on the manuscript;

To my colleagues at the School of Economics and Business Administration, Can Tho University, especially the following individuals: Dr. Vo Thanh Danh for his patient help in offering documents and introducing me to other experts in our working field; Dr. Huynh Viet Khai for his precious advice and encouragement; and Mrs. Huynh Thi Dan Xuan, Mrs. Ta Hong Ngoc, Ms. Vo Anh Tran, and other colleagues and students for their great support in collecting data; and

To Mr. Nguyen HuuThien, IUCN Wetlands Project Co-Manager, for giving me this research problem to solve and for inspiring me with his profound knowledge and his strong commitment to explore and study the wetlands. I dedicate this study to him.

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EXECUTIVE SUMMARY

In recent years, rice intensification in Vietnam has relied on infrastructure developments such as upgrading low dikes into high dikes (dike heightening) in the Mekong Delta floodplain in order to prevent floodwaters from flowing into the fields during the flood season. Due to dike heightening, rice farmers have been able to grow three rice crops in a year instead of two. However, the high dikes have changed the connectivity in the floodplain. These changes due to dike heightening, along with the increase in rice cropping intensity, have broader adverse environmental consequences that have been largely ignored. The consequences include the feedback effects on rice productivity itself and the effects on noncommercial resources in the Mekong Delta (e.g., subsistence floodplain fishery). Thus, investing in dike heightening in VMD has remained a contentious issue among policy and decision makers.

This study conducted a cost-benefit analysis (CBA) of dike heightening in VMD. To gather the data relevant for calculating the costs of dike heightening on rice productivity and pesticide-use externalities, the research team conducted surveys in Vinh Phu and Vinh Binh communes in An Giang province, a rice-intensive province. The former followed the three-crop and high-dike system (intensive cropping); while the latter followed the two-crop and low-dike system (balanced cropping). Comparing these communes enabled the research team to assess the combined impacts of dike heightening and three-rice-cropping system.

The study revealed that the decrease in the intensive crop farmers' profit from the first and second crops was the main cost of dike heightening (54.5% of the total estimated costs of dike heightening), followed by infrastructure costs (28.3%), and the value of foregone revenues from floodplain fishery (16%). The least cost attributed to dike heightening was the increase in pesticide-use external costs (1.2%). However, most of these costs are largely ignored in the official reports related to this infrastructure development.

Based on net present values, dike heightening do not seem to be a viable option for Mekong Delta from both the public and private perspectives. This conclusion was robust to alternative choice of discount rates and alternative assumptions regarding the decrease in rice profits of those following the use of high dikes.

1.0 INTRODUCTION

1.1 Background

Agricultural intensification in the floodplains[1] of delta regions of less-developed countries often goes with upgrading and building of dikes. Dike development in these relatively undisturbed floodplain systems can protect crops and other infrastructure from floods. However, dikes and their associated irrigation systems can considerably affect the nature of the flood as they can fragment the floodplains and interrupt the natural flow of water, sediments, nutrients, and aquatic life. This consequently affects the ecology, environment, and livelihoods of people who depend on fishing and agriculture. This is particularly relevant to the floodplain of the Vietnamese Mekong River, which has high biological diversity and supports a productive agricultural and fisheries sector (MRC 2010).

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[1] Floodplains are defined as those areas that are periodically inundated by the lateral overflow of rivers or lakes, and/or by direct precipitation or groundwater (Junk, Bayley, and Sparks 1989, p.3).

Thus, the overarching question "With the adverse impacts of dike development on a sensitive ecosystem such as the Vietnamese floodplain, is it worthwhile to consider dike development as an infrastructure response to support agricultural intensification?" becomes relevant.

This study focused on the recent flood-dike construction (i.e., dike heightening) in the Vietnamese Mekong Delta (VMD). Dike heightening in the VMD floodplain totally prevents floodwaters from flowing into agricultural fields during the flood season, which is the period of the year when Vietnamese farmers grow the third crop. This study also addressed the ongoing policy debate on the value of investing in dike heightening in order to help maintain Vietnam's position as one of the world's largest rice exporter. The case for the construction of low dikes was not addressed in this study since it is highly improbable that the pre-existing policy that paved the way for the construction of this infrastructure would be reversed—that is, that these low dikes would be demolished to bring the area back into its previous state. The construction of low dikes in Vietnam enabled the country to overcome past food shortages. Likewise, for a long time, Vietnam's improved economic development has been linked to the construction of this infrastructure.

Accordingly, a case study focusing on the cost-benefit case for dike heightening was made in this study. This helped the research team to get insights on the decision-making processes involved in dike heightening and dike management in the VMD floodplain.

The "low-dike system" was used as the base scenario in this study to enable the research team to estimate the differentials between low-dike and high-dike values. The extra costs and the extra benefits incurred due to the conversion of the low dikes into high dikes were the costs and benefits used in the cost-benefit analysis (CBA) calculations. In this study, the direct benefit/primary objective of dike heightening involved the effects of dike heightening on the overall public and private profitability of growing a third rice crop. Meanwhile, the costs of dike heightening estimated in this study included the following:

1. the resulting decrease in profits from the first and second crops in the three-rice-cropping system;
2. the increase in pesticide-use external costs;
3. the foregone revenues from natural floodplain fishery in the high-dike areas due to the loss of flood season inside the high dikes; and
4. the increase in infrastructure costs (i.e., construction, maintenance, and management costs).

For simplicity, the term "balanced cropping" in this study refers to the two-rice-cropping system used in low-dike areas, whereas the term "intensive cropping" refers to the three-rice-cropping system in high-dike areas.

The study is organized as follows. Section 1 reviews the existing literature on the role of floodplains and the impacts of dike heightening. This section also raises the need for an empirical application of the CBA to dike heightening and identifies the main aspects that need to be assessed in the analysis. The dike development situation in An Giang province, which is the site of the case study, is also discussed in this section. Section 2 presents the methodology used in the CBA of this research. Section 3 discusses the CBA results from the perspectives of both the public and private sectors. This section also discusses the sensitivity tests conducted in this research to determine the robustness of the CBA results. Lastly, Section 4 presents the conclusions and recommendations.

1.2 Impacts of Dike Heightening on the Floodplain of the Vietnamese Mekong Delta

There are two main types of dikes in VMD, namely, the park dikes and the farm dikes. Park dikes surround the floodplain-protected areas, while farm dikes surround the villages and rice fields. The term "dikes" in this study refers to the farm dikes only.

The dikes that have been developed in VMD over the last 40–45 years have significantly transformed agricultural production in the region. Likewise, these infrastructure developments have been closely associated with the recent initiatives to shift from balanced cropping to intensive cropping in the floodplain. A few decades ago, the cropping system in the floodplain consisted of cultivating one floating rice crop during the flood season. Although this cropping system was environmentally benign, it provided low yields for Vietnamese farmers (Nguyen 2012).

Floodplain agriculture is now more intensified. With the construction of the dikes, the previous cropping system was replaced by the two-rice-cropping system in the low dikes and three-rice-cropping system in the high dikes; these systems have become the dominant types of land use in the delta (Le et al. 2007). High dikes totally prevent floodwater from flowing into the fields and low dikes delay the effects of flooding, which have enabled the farmers in VMD to intensify their rice production. Accordingly, these intensified farming systems have transformed Vietnam from a rice importer to one of the world's largest rice exporters. The Ministry of Agricultural and Rural Development (MARD) of Vietnam believes that the benefits from the third rice crop outweigh the costs, including the damages caused by dike breaching (Nghe 2011).

When dike heightening alters floodplain hydraulics, they can also alter the floodplain ecosystem values. One of the key benefits of Mekong floodplains is that it provides resources for the agriculture and fishery sectors, which are both essential for local livelihoods, and thus have large economic values (Baran et al. 2005; MRC 2010). Dike heightening therefore raises the concern as to whether the intensified rice production obtained from the third rice crop may come at the cost of ecological sustainability, which is necessary to maintain productivity of both rice and fishery production.

Thus, the issue of dike heightening is controversial, especially when the impacts of high dikes and the intensified rice production in the floodplain are considered (IUCN 2011b). This then raises the question as to whether the economic benefits that such infrastructure brings to farmers are sustainable (Buu 2013). Even experts from the Dutch government, who assisted in building the high dikes in VMD in the 1990s, now recommend restoring the floodplain to its natural state or using the two natural depression areas in the Plain of Reeds and the Long Xuyen Quadrangle to store floodwater during the flood season in order to reduce the flood peak discharges in VMD and to regulate saline water intrusion during the dry season (MNRE and MARD 2013).

A number of empirical studies have shown evidence of the environmental problems in VMD due to dike heightening. The studies of Hashimoto (2001), Le et al. (2008), and Nguyen (2012) showed that the fishes that naturally move downstream to VMD during the flood season have been lost, and consequently have been replaced in value by the third crop.

Dike heightening can also result in loss of biodiversity, particularly loss of natural fish. A study in China found that natural fish can act as a bio-control agent in rice (Xie et al. 2011). Likewise, dike heightening can result in the loss of natural flood sediments, which possess a balanced formula of complex nutrients (Duong et al. 2010); and loss of natural mechanism to flush out toxins in the high-dike areas (Pham 2011). All of these create unfavorable conditions for rice cultivation, and consequently negatively impacts rice productivity.

Likewise, planting three rice crops continuously is against good agricultural practices. For example, it is not recommended in integrated pest management (IPM) as IPM encourages crop rotation and long fallow periods. A study conducted in 1999 in the Mekong Delta found that farmers who followed the two-rice-cropping system had slightly higher rice yields per crop and higher income per crop, as compared to those who followed the three-rice-cropping system (Berg 2002). The negative impacts of the latter system on rice productivity were further confirmed by a long-term three-rice-cropping experiment (i.e., 24 years) in the Philippines (Dobermann et al. 2000). Cumulatively, Dobermann et al. (2000) showed that yields had decreased by 38%–58% within the 24-year period of growing three rice crops a year. The average yield reduction ranged from 1.4%–1.6% for each crop per year.

Intensive use of agro-chemicals in crop cultivation is a characteristic of rice intensification triggered by dike development (NCST 2005). Rice intensification may also drive farmers to apply more pesticides and fertilizers per crop. Howie (2011) reported a 40% difference in rice yield per ton of fertilizer between rice plantations in low-dike and high-dike areas in sites where high dikes had been built for more than 10 years. Huynh (2011) argued that farmers with rice monoculture had more expenditure per rice crop than those farmers with rice rotation and intercropping. This may be because rice monoculture causes the soil to be less fertile. Overusing fertilizers has also led to higher pest and disease infestation, which consequently drives farmers to use more pesticides (Huan et al. 2005).

Economic studies on dike heightening are very limited. Although Duong et al. (2004) reviewed the environmental and socioeconomic impacts of dikes, the authors did not provide robust models that could predict the agricultural effects under different dike management scenarios. A more recent study by Do (2008) estimated the impacts of the changes in dikes on both market and nonmarket values. However, the author focused only on the reduction of rice output as the cost of converting high dikes back into low dikes. Specifically, Do (2008) found that the proposed conversion of high dikes into low dikes and the wetland management implemented in Tram Chim National Park would reduce rice yields by 0.03 ton per hectare (t/ha) per year; but the benefits—in terms of biodiversity values—would outweigh the costs. Thus, park dike conversions would generate a net social benefit.

On the external costs of pesticide use, Dang and Gopalakrishnan (2003) calculated the value loss in rural water resources due to pesticide contamination in the Mekong Delta to be about USD 251 million. With respect to the negative effects of pesticide on human health, more than 7,000 cases of food poisoning due to ingestion of pesticide residues were reported in Vietnam in 2002, which had caused 277 deaths in more than half of the provinces in Vietnam. It has also been suggested that as many as 2 million Vietnamese farmers could have suffered from chronic pesticide poisoning in 2005 (Pham 2010). These support the findings of Dasgupta et al. (2007), where the authors found that 35% of the farmers whose blood were tested had been detected with acute pesticide poisoning, whereas 21% had been detected with chronic poisoning.

To the author's knowledge, a study that analyzed and compared the external cost of pesticide-use across different farming systems has yet to be conducted. One reason that may explain the lack of such study is because the method that makes such comparisons possible, i.e., the pesticide environmental accounting (PEA), has just been recently introduced in 2008.

Because no economic analysis of dike heightening has been done yet, this study attempted to conduct a CBA of dike heightening in An Giang province, Vietnam to fill that research gap.

1.3 Significance of the Study

To estimate the costs and benefits of dike heightening in the VMD floodplain, the author used the profit from the third crop and the construction costs in the conversion of the low dikes into high dikes as the straightforward benefit and cost of dike heightening, respectively. In addition, the author based the other two costs of dike heightening on the literature review on the impacts of dike heightening discussed the previous section. These costs are: the costs imposed on local farmers due to profit loss in rice production and the external cost of pesticide use imposed on society.

1.3.1 Costs imposed on local farmers due to profit loss in rice production

In the VMD floodplain, the three-rice-cropping system is impossible to follow in the low-dike areas. Thus, the profits from the first and second crops in the high-dike areas were compared with that of the low-dike areas in order to estimate the decrease in profit due to dike heightening. Accordingly, the impact of dike heightening on rice profit was determined using a translogarithmic (translog) profit function that considered the effect of dike heightening as a dummy variable. To get the information needed for this estimate, the research team conducted surveys among 110 farms in a high-dike area with three rice crops, and among 99 farms in a nearby low-dike area with two rice crops.

The implications of the resulting economic costs on rice production determined by this study can help those rice farmers who contribute the most but earn the least in justifying their concerns against those groups with vested interests.

1.3.2 External cost of pesticide use imposed on society

The impact of pesticide use was determined in this study by determining the increase in the external costs of pesticide use. This included the total external cost of pesticide use incurred by having one more crop (i.e., the third crop) and the increase in the external cost of pesticide use incurred from the first and second crops inside the high dikes (as compared to those outside). The PEA methodology was applied. PEA is a method for estimating the external costs of a pesticide application based on the ecotoxicology, environmental behavior, and application rate of an active ingredient (Leach and Mumford 2008).

The information on the application rate of all active ingredients was obtained from the same abovementioned surveys. Accordingly, the resulting external costs of a particular pesticide ingredient used in the different rice farming systems can also be used in identifying those pesticides with the largest indirect costs. This would then help the stakeholders achieve their pesticide rationalization targets. Likewise, this information can be used in predictive or retrospective assessment of introducing new standards or choosing alternative technology and in the assessment of alternative pesticide-related policies.

Increase in fertilizer use also causes externalities such as the blue baby syndrome in infants (Tegtmeier and Duffy 2004). However, this study estimated the externalities of pesticide use only, and not the overall external cost of using agro-chemicals.

The main goal of this study is to be able to present to policy makers a reliable set of estimates of the costs and benefits of dike heightening in the VMD floodplain so that decisions can be made to improve the social welfare in the area. However, dike heightening may result in changes in other floodplain values. For example, the regulating role of floodplains, which helps reduce flooding in other areas in the delta while replenishing underground water supply for supplementing rivers and canals supplies during the dry season, has been negatively affected by this infrastructure development (Pham 2011; IUCN 2011a; Buu 2013). Therefore, the findings of this research should be considered as output of a partial cost-benefit analysis.

1.4 Description of the Project Site: An Giang Province

An Giang province, Vietnam is on the northwest of Mekong Delta. This province is a rice-intensive province where major dike-heightening developments have been implemented over the past 10 years. The floodplain lies in the Plain of Reeds, a vast wetland covering the northern parts of Dong Thap, Tien Giang, and Long An provinces; and the Long Xuyen Quadrangle (LXQ) (Figure 1). An Giang is located at LXQ and shares borders with Cambodia (northwest), Dong Thap province (east and northeast), Kien Giang (south and southwest), and Can Tho City (southeast) (Figure 1).

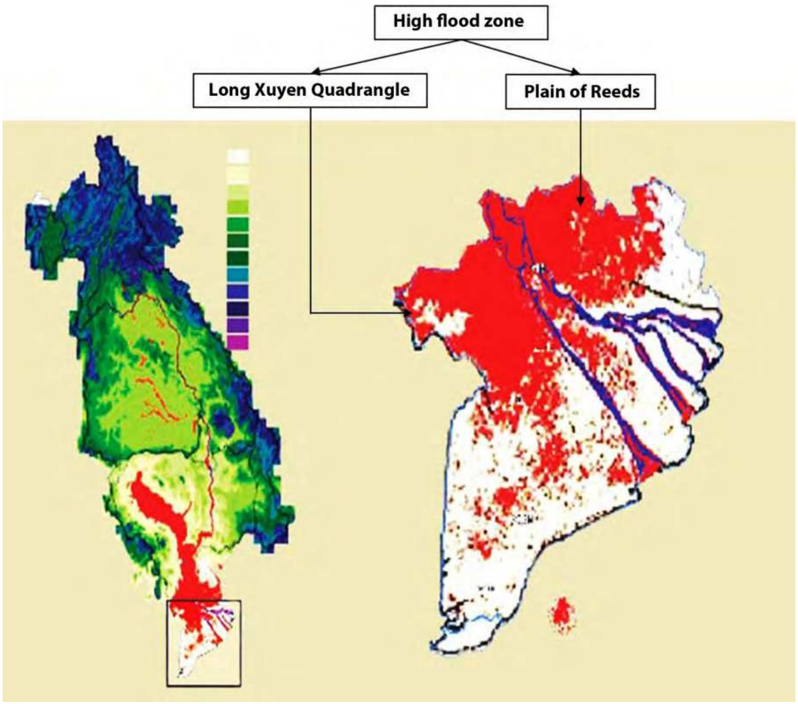

Figure 1. Flooded area (in red color), beginning of September 2000, Mekong Basin and Mekong Delta
Source: Le et al. (2007)

An Giang's population is 2,153,716 individuals, 70% of which are living in the rural area. The total land area of An Giang is estimated to be 353,670 hectares (ha), 79% of which are used for agricultural production (AGGSO 2012).

Vinh Phu and Vinh Binh are the two communes in An Giang that were selected as the specific study sites of this research (Section 2.3.1 discusses in detail how these two communes were selected). These two communes are located in close proximity to each other, with only a canal separating them (Figure 2).

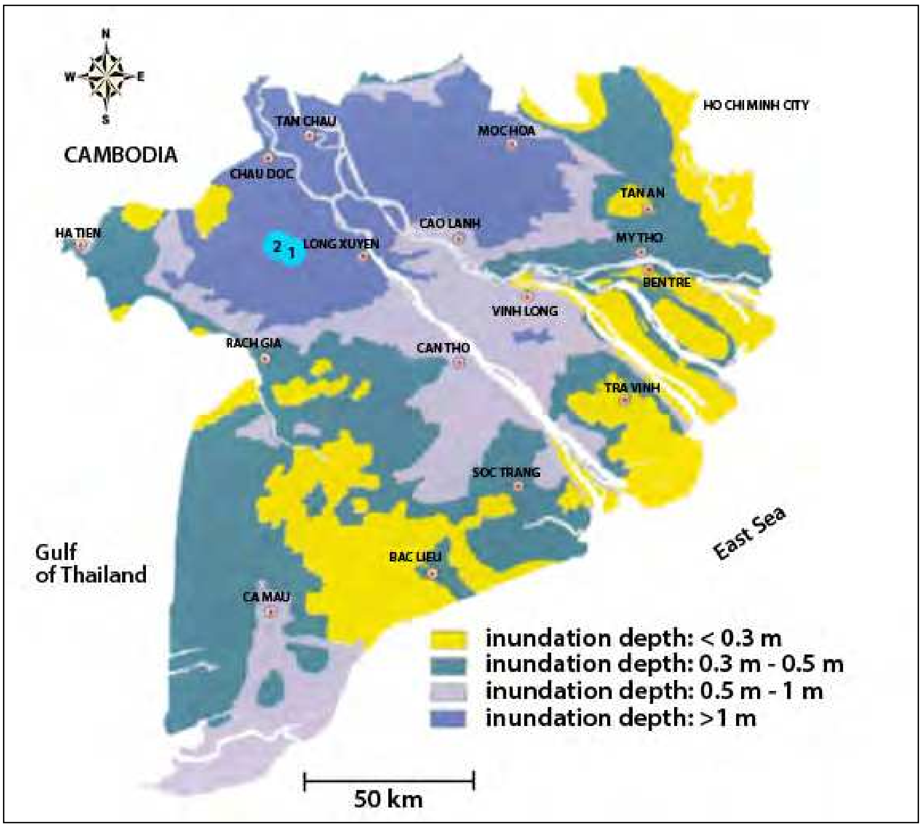

Figure 2. Map of the study site
Source: Vo and Matsui (1998)

Vinh Phu is located in Thoai Son district, which has a total population of 181,194 individuals. About 137,600 of its populace are residing in the rural areas. It has a total land area of 46,886 ha, 83.8% (39,299 ha) of which are used for rice farming. Farmers in the district plant three rice crops per year and yield about 6.47 t/ha annually. Meanwhile, Vinh Binh is located in Chau Thanh district, which has a total population of 170,817 individuals, with 146,325 of them residing in the rural areas. Its total land area is 35,506 ha, with 29,222 ha (82.3%) planted with rice. Chau Thanh farmers plant two rice crops per year, and yield an average of 6.31 t/ha per year.

1.4.1 Hydro-meteorological facts affecting rice production in An Giang province

An Giang is situated in the tropical monsoon region and has an annual average temperature of 27.8°C. About 88% of the annual rainfall volume occurs during the rainy months of May to November. During the rainy season (usually mid-August to late December), the upstream water of the Mekong River flows to the province; this results in the annual flood season that inundates about 70% of the natural land of the province under 1.0–2.5 meters (m) of floodwater (AGSDI 2009).

On the other hand, the dry season is from December to April, which is usually accompanied by water shortages for agricultural production and for domestic use, especially in the high areas. The water shortage during the dry season is further exacerbated by high water evaporation of 1,200–1,300 millimeters annually. The hydrology of An Giang depends mainly on the semi-tidal system of the East Sea, and it is affected by the Tien and Hau river streams, rainfall, morphology characteristics, and river canal systems. The Mekong River from the Tien and Hau rivers provides An Giang with an annual average flow of 13,500 cubic meter per second (m^3/s); 24,000 m^3/s happens during the flood season, and 5,020 m^3/s during the dry season (AGSDI 2009).

Rice production in An Giang is associated with annual floods, which are classified as early flood and main flood. Early floods occur in July and the peaks of the main floods come in September and October (Bui 2012). Farmers name their rice crops as winter-spring crop (the first crop), summer-autumn (the second crop), and autumn-winter (the third crop) (AGSDI 2009).

The first crop starts in November/December, after the annual flood season ends, and then completes in February/March. At the beginning of the season, water is pumped out of the field for sowing and then pumped in to irrigate the farm areas for the whole season. The second crop starts at the end of April or beginning of May, and is harvested at the end of July or early August before the early flood comes. Water is pumped in for the whole season; in case of heavy rains or early floods, water is pumped out at the end of the season and low dikes have to be consolidated. The third crop follows the second crop, and harvests come in October/November at the end of the annual flood season. For the third crop, high dikes have to be consolidated and upgraded, and water is pumped out the whole season.

1.4.2 Dike heightening in An Giang province

Low-dike construction (first stage). The low-dike systems in the Mekong Delta were constructed based on the flood peak in 1978 and on the average height of the Mekong Delta flood (~1 m). The low dikes had to be between 2–4 m (usually 3 m) tall to be able to control the early floods and thereby protect the second crop. After harvesting, all the culverts are opened so that floodwater flows into the field. When the main flood comes in September/October, the dikes overflow and the floodplain becomes inundated until November (Bui 2012). From 1976 to 2000, the length of the dike system was 3,900 kilometers (km), which surrounded 432 subareas. As a result, almost all of the 200,000 ha of farm areas with two rice crops were protected from the August flood each year (Doan 2012).

High-dike construction (second stage). The high-dike systems were built by overtopping or increasing the height of the low dikes. They are higher than the peak height of the flood in 2000, and can protect the third crop during the peak discharge of the main flood (AGSDI 2009), which is usually 1 m higher than the early flood in September and October (Bui 2012). As a result, the areas with intensive cropping have increased from 18,855 ha in 2001 to 149,542 ha in 2012 (AGSDI 2013).

At present, the intensive-cropping system in An Giang has been criticized (IUCN 2011b). Local authorities[2] have even suggested limiting rice production just enough for domestic consumption considering the high maintenance cost of the dikes shouldered by the provincial authorities, the low profits gained by the farmers, and the other associated environmental costs.

Based on official reports related to high dikes and irrigation works, the annual flood that occurs in VMD is considered as a normal hydrological phenomenon. For example, one report from the An Giang Sub-department of Irrigation (AGSDI) stated that the advantages of flood are fertile sedimentation, field flushing, improvement of soil and water quality, complementation of ground water, natural fishery, and employment for some farmers (AGSDI 2009). However, these reports largely ignored the fact that the high dikes have failed to maintain the benefits provided by flooding. These reports likewise failed to mention that high dikes have exacerbated the environmental problems caused by the three rice crops, as suggested in the research studies of Hashimoto (2001), Howie (2005), Pham (2011), among others. For example, the same AGSDI report cited the objective of implementing absolute flood control in the province in order to enable more than 190,000 ha of farm area to be planted with the third crop in 2015 by dealing with the flood's disadvantages such as "interrupting people's socioeconomic activities, destroying infrastructure, badly affecting production

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[2] This was the feedback of Mr. Huynh Minh Nhi (former Chair of An Giang province) on the Mekong Delta Plan (MDP). This was cited in the report prepared by Mr. Nguyen Huu Thien, which documented the proceedings of the stakeholders consultations regarding the MDP.

and harvesting calendar, as well as gross output of agricultural and aquaculture products, obstructing the modernization, and industrialization of rural areas" (AGSDI 2009).

2.0 METHODOLOGY

This section discusses the costs and benefits included in the CBA calculations. It reviews the use of profit function and PEA techniques for assessing the impacts of dike heightening on rice profit and on pesticide-use externalities for estimating the mentioned costs. This section also discusses the data collection methods used in this study and the criteria for choosing the study sites that enabled the research team to get the information needed for the CBA.

2.1 Cost-Benefit Analysis

Dike heightening creates various benefits and costs in An Giang province. This study focused on the direct benefit of dike heightening, namely, the effects of dike heightening on the overall social and private profit of growing a third rice crop.

Four costs due to dike heightening were estimated in this study as follows:

1. the decrease in profit from the first and second crops in high-dike areas;
2. the increase in pesticide-use external costs;
3. the foregone net revenues from natural floodplain fishery due to the loss of floodplain area in the high-dike areas; and
4. the increase in infrastructure costs (construction, maintenance and management costs).

The "low-dike system" was used as a base scenario to allow the author to compute the differentials between low-dike and high-dike values.

As the benefits and costs occur at different times or can change with time, the CBA estimates the increased net present value (NPV) from dike heightening as follows:

$$\Delta\, NPV = \sum_{t=1}^{15} \frac{(\Delta NPB_t - \Delta NPC_t)}{(1+r)^t}$$

Equation (1)

where:

$\Delta\, NPV$ = the total extra net present value due to the conversion of low dikes into high dikes over the 15-year lifespan of the high dikes;

$\Delta\, NPB_t$ = present value of the extra benefits due to dike heightening in year *t,* equivalent to the profit of the third crop in high dikes enabled by dike heightening ('000 VND/ha);

$\Delta\, NPC_t$ = present value of the extra costs due to dike heightening in year *t* ('000 VND/ha); and

r = discount rate.

The costs calculated in this study included the following:

$\Delta\, \pi^*$ = decrease in profit from the first and second crops in the high-dike areas,

$\Delta\, TEC$ = increase in pesticide-use external costs,

$\Delta\, FC$ = foregone revenues from floodplain fishery during flood season,

$\Delta\, CC$ = increase in infrastructure costs due to dike heightening, and

r = discount rate.

This study examined the impacts of dike heightening over a 15-year time horizon. This time horizon was selected based on the advice of the Vice Head of Department of Irrigation during a personal interview with the research team. To the author's knowledge, there is no document available that cites the lifespan of an earth river dike.

In dike heightening, all of the different structures of the irrigation system (e.g., canals, culverts, low and high dikes, pump station etc.) are important as they are connected to one another. Any break in the closing system would eventually damage the crops. The irrigation system in VMD, therefore, must be a synchronized dike system that not only contributes to the use, exploitation, protection, and development of water resources, but also controls and limits the damages caused by water such as flood and salinity intrusion. Accordingly, the terms "irrigation system" and "dike system" are interchangeable in this study.

The high-dike system in VMD was completed and became fully operational in 2012. Calculating the costs and benefits of the incomplete high dikes during the construction period is very complex. Thus, to be conservative, the author assumed that the completed high-dike system would have a lifespan of 15 years (i.e., 2012–2026). Farmers would then enjoy the benefits gained from planting the third crop enabled by the high dike within this 15-year period. Meanwhile, the infrastructure cost would be the cost incurred during the construction period from 2001 to 2012. For simplicity, the period 2001–2012 would be named as the "construction period", while 2012–2026 would be the "benefit period."

To calculate the decrease in profit from the first and second crops in the high-dike areas ($\Delta\pi^*$) and the increase in pesticide-use external costs (ΔTEC), the valuation techniques discussed in the next section were applied in this study.

2.2 Valuation Techniques

2.2.1 Profit function

Based on the literature review on dike heightening, there are two possible hypotheses that may explain the cause of economic losses in rice production due to dike heightening in terms of reduced yield and increased input costs. They are as follows:

1. The increase in environmental pollution (water and soil) and decrease in production efficiency consequently decrease rice yield.
2. Although some measures can be used to offset the possible losses in productivity due to dike heightening, these measures have implementation costs that may be costly to farmers.

The basic profit function is as follows:

$$\pi^* = \pi\,(W^*, C, Z, E, D) \qquad \text{Equation (2)}$$

where:

π^* = normalized net revenue or normalized profit, which is defined as the gross revenue minus variable cost divided by the farm-specific output price;
W^* = vector of the variable input prices divided by output price;
C = vector of fixed factors of the farm;
Z = vector of socioeconomic characteristics of farmers;
E = vector of farming conditions; and
D = dike heightening factor (intensive cropping = 1, balanced cropping = 0).

The loss in the net economic return due to dike heightening is defined by the difference in the net economic return between intensive cropping and balanced cropping. It can be estimated by the equation:

$$\Delta\pi^* = \pi(\overline{W^*}, \overline{C}, \overline{Z}, \overline{E}, D = 0) - \pi(\overline{W^*}, \overline{C}, \overline{Z}, \overline{E}, D = 1)\,. \qquad \text{Equation (3)}$$

where:

$\Delta\pi^*$ = profit loss (in '000 VND/ha);
$\overline{W}^*$ = average prices of inputs;
$\overline{C}$ = average of fixed factors;
$\overline{Z}$ = average of socioeconomic characteristics of farmers;
$\overline{E}$ = average of farming conditions; and
D = dike heightening factor (intensive cropping = 1, balanced cropping = 0).

The following translog profit functional form was then used to estimate the changes in producer surplus as a result of dike heightening:

$$\ln\pi^* = \alpha_0 + \sum_{j=1}^{5}\alpha_j \ln W_j^* + \frac{1}{2}\sum_{j=1}^{5}\sum_{k=1}^{5}\tau_{jk}\ln W_j^* \ln W_k^* + \sum_{j=1}^{5}\sum_{l=1}^{2}\phi_{jl}\ln W_j^* \ln C_l + \sum_{l=1}^{2}\beta_l \ln C_l \qquad \text{Equation (4)}$$
$$+ \frac{1}{2}\sum_{l=1}^{2}\sum_{t=1}^{2}\varphi_{lt}\ln C_l \ln C_t + \sum_{m=1}^{4}\varpi_m Z_m + \sum_{n=1}^{3}\eta_n E_n + dD$$

where:

π^* = restricted profit or restricted net revenue (total revenue minus total cost of variable inputs) normalized by price of output (P);
W_j^*, W_k^* = price of the j^{th} input (W_j) or k^{th} input (W_k) normalized by the output price (P), $j = k$;
W_1^* = normalized price of fertilizer;
W_2^* = normalized wage of labor;
W_3^* = normalized price of the machine power;
W_4^* = normalized price of seed;
W_5^* = normalized price of pesticide;
C_l, C_t = quantity of fixed input, $l = t$;
C_1 = land cultivated (in ha);
C_2 = number of working age labor;
Z_1 = age (years);
Z_2 = gender (1 = male, 0 = female);
Z_3 = the number of school year (years);
Z_4 = attendance in training sessions (1 = Yes, 0 = No);
E_1 = variable of serious disease incidence happening during the studied year (1 = Yes, 0 = No);
E_2 = variable for soil quality (1 = fertile soil, 0 = other soils);
E_3 = variable for off-farm income ratio (in %); and
D = dike heightening factor (intensive cropping = 1, balanced cropping = 0).

The fixed factors may include the land cultivated, the number of working age labor in family, and farm capital used (Rahman 2003).

In the present study, machine power price is the rented machine price, which is a variable factor. Only few farmers own machine, and thus cannot be considered as "farm capital used" or a fixed factor similar to that of in other studies.

Then, the following restriction was applied to test whether the translog function form was suitable or not:

$$\tau_{jk} = \phi_{jl} = \varphi_{lt} = 0 . \qquad \text{Equation (5)}$$

2.2.2 Cost-transfer method (pesticide environmental accounting)

Dike heightening will more than likely increase the external costs of pesticide use. This is due to the additional external costs of pesticide use incurred during the third crop and the increase in the external costs of pesticide use incurred during the first and second crops.

This was then estimated by the following equation:

$$\begin{aligned}\Delta TEC &= \Delta TEC_{DX} + \Delta TEC_{HT} + TEC_{TD} \\ &= (TEC_{DX,HD} - TEC_{DX,LD}) + (TEC_{HT,HD} - TEC_{HT,LD}) + TEC_{TD,HD}\end{aligned} \qquad \text{Equation (6)}$$

where:

ΔTEC = increase in total pesticide-use external cost,

ΔTEC_{DX} = increase in pesticide-use external cost of the first crop as compared to that in balanced cropping,

ΔTEC_{HT} = increase in pesticide-use external cost of the second crop as compared to that in balanced cropping, and

TEC_{TD} = pesticide-use external cost of the third crop in the intensive cropping.

The existence of the difference in the external cost of pesticide-use for each crop between intensive and balanced cropping could not be tested. This was because the external costs were calculated by totaling all the pesticide-use values of the farm households, and then dividing the total by the total households in order to get the average external cost per household. This did not yield relative standard errors or actual external cost for each household.

Instead, the author tested whether there was a difference between the amount of active ingredients in the pesticides used by balanced crop farmers and that by intensive crop farmers. This is one of the factors needed in calculating the external costs of pesticide use. The difference was analyzed by comparing the means using the t-test, and by comparing the medians using the Wilconxon rank-sum test. The author conducted all analysis using STATA 10 software package.

The external costs for each crop were calculated as follows:

Due to the lack of data on pesticide-use external costs in Vietnam, the author applied the PEA method. The PEA tool combines the environmental impact quotient (EIQ) (Kovach et al. 1992) with absolute estimates of external pesticide costs in the UK, USA, and Germany (Pretty et al. 2000). The PEA tool then converts these external costs of pesticide use into comparable values with that of other countries by adjusting for economic conditions. This is the only method capable of comparing the external costs of pesticide use across different farming systems (Praneetvatakul et al. 2013).

The total external costs for each crop of a farming system can be calculated as follows:

$$TEC = \sum_{p=1}^{m} \left[A_p x p\_active x \sum_{c=1}^{8} \left[EC_c x F_c x (F_{agemp} \middle| c = 1,2) \right] x F_{gdppc} \right] \qquad \text{Equation (7)}$$

where:

A_p = application rate (kg/ha) of a pesticide p for a total of m pesticides;

p_active = proportion of active ingredients;

EC_c = external cost base values [taken from Leach and Mumford (2008) and then converted to 2012 VND values]; absolute estimates of external costs using data presented in Pretty et al. (2000);

F_c = toxicity level of pesticide (0.5 = relatively low level of toxicity, 1.0 = medium toxicity, and 1.5 = highly toxic);

c = category c of the eight categories that were evaluated in developing the EIQ model;

F_{agemp} = ratio of Mekong Delta's share of employment in agriculture to the average share of agricultural employment in Germany, UK, and US (weighted by GDP); and

F_{gdpc} = ratio of Vietnam's per capita GDP to average per capita GDP in Germany, UK, and US (weighted by GDP).

The different steps that the author undertook to calculate *TEC* is presented in Appendix 1**.**

In summary, the research team needed to collect the following data set per crop system to be able to estimate the external costs associated with pesticide use in VMD: (1) application rate (kg/ha) of each pesticide, and (2) name and proportion of active ingredients in each pesticide. The research team also obtained secondary data from Cornell University web and from the study of Leach and Mumford (2008) to calculate the external costs.

However, there were possible distortions in the estimation due to the following assumptions of the PEA approach:

1. The external costs obtained from Pretty et al. (2000) were conservative, and thus would likely underestimate the total negative impacts of modern agriculture. The PEA model uses two proxy variables to adjust the external costs of pesticide use in different countries, namely, comparative GDP per capita (F_{gdpc}) and the proportion of population engaged in agriculture (F_{agemp}). These variables allowed the researchers to use the method for Vietnam where pesticide poisoning data were not available. However, including F_{gdppc} decreases the monetary cost of pesticide use in the case of Vietnam because the costs of remediation are relatively higher in the three developed countries originally examined, as compared to that in a developing country like Vietnam. Conversely, including F_{apemp} increases these relative costs in the case of Vietnam.
2. The PEA model redistributes these different external cost categories among the EIQ categories although, inevitably, perceptions would differ with regard to the distribution of costs from one system to another.
3. The PEA model does not account for the differences in eco-toxicological and environmental behavior of an active ingredient in the different formulations.

Despite these constraining assumptions, the PEA model can provide a systematic framework for a wide range of pesticide-related decisions (Leach and Mumford 2008). Thus, it was possible to compare the external costs of pesticide use between balanced cropping and intensive cropping for data input into the CBA of dike heightening.

However, a drawback of EIQ (and accordingly, the PEA model), which may have limited the estimates of the external costs of pesticide-use in high-dike areas in this study, is it fails to make use of site-specific conditions. In other words, the important relationship between dike heightening and the risk of exposure to pesticide use—particularly on the changes in soils and hydrology associated with dike conversion (e.g., no flushing out of toxins inside high dikes) and the changes in the way farmers handle pesticides when increasing cropping intensity—was not be captured in this study.

2.3 Data Collection Methods and Procedures

2.3.1 Primary data

The author used primary data as inputs for the CBA. Survey data were used to calculate the profit from the third rice crop, while the decrease in profit from the first and second rice crops were estimated using the profit function. The survey data on pesticide use were also the data used in the cost-transfer method via the PEA method.

The research team conducted the surveys from November 2011 to October 2012. Enumerators included students and staff from the School of Economics and Business Administration, Can Tho University.

To calculate the profit loss and pesticide-use external costs through the valuation techniques discussed in Section 2.2, the discussion below describes the criteria followed in this study in order to select the appropriate study sites for the survey. Specifically, two study sites in the VMD floodplain were selected: one site that applies intensive farming, while the other applies balanced cropping.

1. The two study sites should be rice intensive and should have had similar social and natural conditions, such as fertile soil. They should also have had experienced the same flood levels before the construction of the high dikes.
2. The study should be far from cities and district centers. Agricultural land in urban areas may be reallocated to other uses in the future, and thus may not be representative of rural villages. Also, farmers located in urban areas may not be representative of rural farmers in the Mekong Delta.
3. One of the sites should be doing the three-rice-cropping system in the high-dike areas for 10 years or more. The intensified rice-based effects would then be accumulated long enough to reflect the differences in rice productivity.
4. The two areas should be far enough from each other in order to limit any spillover effects (e.g., pesticides and fertilizers application).

Note that there is a trade-off between the first and the last criteria—it is highly improbable to satisfy both items at the same time. Thus, the study team decided to select the two subsamples that satisfied the first three criteria, but these selected sites were expected to suffer from spillover effects because the two sites are closely located to each other. The study team divided the sample into two in order to determine the impact of dike heightening on the rice productivity of intensive crop farmers. However, the spillover effects due to the intensive use of pesticides and fertilizers in intensive cropping may have also imposed additional costs on the balanced cropping located in the nearby area. Hence, these effects would have likely weakened the dike-heightening impact in the calculation. In other words, ignoring these spillover costs would likely make the calculation more conservative.

The study team selected Vinh Phu and Vinh Binh communes as the two subsamples in An Giang province. In each area, farmers were chosen randomly from the list of rice farmers provided by communal authority. The first group consisted of 110 three rice crop farmers from Vinh Phu commune (Thoai Son district), which represented the high-dike area. The second group consisted of 99 two rice crop farmers from Vinh Binh commune (Chau Thanh district), which represented the low-dike area.

The assumption was that rice production in the two communes used to have homogenous characteristics. Accordingly, using the profit function for the dike-heightening impact dummy variable described in Equation 4 enabled the author to measure the profit loss due to dike heightening.

Rice farmers were interviewed at each study site using two separate structured questionnaires (See Appendices 2 and 3). These questionnaires were designed to collect data on production area, yield, and input uses in order to estimate the profit loss due to the effects of dike heightening on rice productivity and to obtain the pesticide-use data input for the PEA calculation.

The information needed for determining rice productivity and pesticide use was detailed. It required the name, amount, and application rate for each pesticide used in the farm areas. Due to the length of the interviews, which may negatively affect the quality of the respondents' answers, the questionnaire was divided into two parts; each part took about 60 minutes to complete. A short break in between was required to ensure the quality of the respondents' answers. The first part of the questionnaire focused on household-level information regarding damages to and losses from rice production. The second part focused on detailed pesticide use relative to its potential environmental impact.

2.3.2 Secondary data

This study also used secondary quantitative data. The data on the capital, maintenance, and management costs of dike heightening were sourced from AGSDI. The data on the net foregone revenues from natural floodplain fishery were speculated based on the fish study of Le and Nguyen (2000) and on related data from the Statistical Yearbook of An Giang Statistics Office for the period 2000–2012 (AGGSO 2006; AGGSO 2010; AGGSO 2011; AGGSO 2012).

In addition, this study employed a GDP deflator (GDPD) and adjusted the prices in the different years for inflation in order to be comparable with 2012 prices. GDPD is the ratio of nominal GDP to real GDP (Blanchard and Sheen 2004). The values of GDPD from 2000 to 2012 were obtained from the World Bank

(2013a) database. The exchange rate in 2012 was used to convert Vietnamese currency to US dollars (i.e., USD 1.00: VND 20,828) (World Bank 2013b).

3.0 RESULTS AND DISCUSSION

3.1 Translog Profit Function Model

Table 1 summarizes the estimated translog profit function model used in this study.

Table 1. Descriptive statistics of the variables used in the rice profit models

Variable	Low-Dike Area	High-Dike Area	t-ratio	Whole Sample
Output, Profits, and Prices				
Rice output (t)	6.95 (0.84)	6.99 (0.81)	−0.39	6.97 (0.82)
Rice price (‘000 VND/t)	5,318.78 (557.98)	4,406.01 (526.87)	12.16***	4,838.38 (707.72)
Fertilizer price (‘000 VND/kg)	11.36 (1.31)	11.90 (1.62)	−2.63***	11.64 (1.50)
Labor wage (‘000 VND/day)	81.34 (62.42)	98.37 (97.43)	−1.48**	90.30 (82.97)
Machine power price (‘000 VND/ha)	5,145.02 (1,580.58)	4,407.41 (1,099.34)	3.94***	4,756.80 (1,395.23)
Seed price (‘000 VND/kg)	13.01 (1.67)	9.52 (4.28)	7.58***	11.17 (3.73)
Pesticide price (‘000 VND/kg of active ingredients)	1,490.56 (452.29)	1,365.05 (586.28)	1.71***	1,424.50 (529.58)
Land cultivated (ha)	1.93 (1.74)	2.02 (1.53)	−0.39	1.97 (1.63)
Number of working age labor in family (individuals)	3.38 (1.53)	3.85 (1.78)	−1.94***	3.62 (1.67)
Farm-Specific Variables				
Age (years)	44.17 (11.72)	44.09 (10.51)	0.05	44.12 (11.07)
Gender (male = 1, female = 0)	0.96 (0.17)	0.97 (0.16)	−0.13ψ	0.97 (0.16)
Education (years)	6.21 (3.05)	6.07 (3.16)	0.30	6.14 (3.10)
Training (training = 1, otherwise = 0)	0.31 (0.46)	0.27 (0.44)	0.67ψ	0.29 (0.45)
Soil rank (fertile soil = 1, otherwise = 0)	0.90 (0.29)	0.77 (0.42)	2.60***ψ	0.83 (0.36)
Disease (disease = 1, otherwise = 0)	0.54 (0.50)	0.71 (0.45)	−2.59***ψ	0.63 (0.48)
Non-agricultural income share (%)	0.17 (0.19)	0.08 (0.15)	2.13**Ψ	0.12 (0.18)
Dike-heightening effect (intensive cropping = 1, balanced cropping = 0)	0.00	1.00		0.52 (0.50)
Number of observations	99.00	110.00		209.00

Notes: (1) ***, **, * indicate statistical significance at 1%, 5%, and 1% levels, respectively, using t-test for comparing means; (2) ψ = Z-ratio for two group test of proportions; (3) ( ) indicates standard deviation; (4) The Wilconxon rank-sum test was used to compare medians; it shows the same results except for labor wage. Labor wage shows no statistical significance at 1% significance level using Wilconxon rank-sum test; (5) All variables are averages of all farmers’ profits from the first and second crops, excluding the third crop, to make the estimates comparable between the two cropping systems.

On average, both intensive and balanced crop farmers cultivated in similar area of land, and achieved 6.97 tons (t) of rice output per hectare from the first and second crops. However, switching to intensive cropping is not as simple as adding one more crop (third crop). It also involves changing the whole system's characteristics and quality (i.e., water management, cropping calendar, etc.), which demand different input combinations. Consequently, the farmers in the two areas incurred different average prices per average unit amount of inputs. For example, the high dikes—like any other large-scale water-control structures—have been built in the Mekong Delta to create ecological conditions that are relatively uniform and can be easily controlled in order to enable intensive cropping. Thus, it is less difficult to operate machines in the high-dike areas than in the low-dike areas, which results in cheaper machine rent in the former than in the latter.

Regarding the cheap seed varieties, it was found that farmers planted rice varieties with average to high levels of resistance to diseases and insects. These varieties can also tolerate unfavorable environmental conditions such as low soil pH. However, these varieties have low commercial value and restricted export market; thus, their selling prices were significantly lower than that of other rice varieties. These rice varieties may have been made available because rice farmers in high-dike areas had to cope with unfavorable conditions for rice cultivation. For example, by following the intensive-cropping system, the third crop provides a way for pests and plant diseases to damage the crops in the next cropping season due to the short fallow period between rice planting. Moreover, the short fallow period can also cause organic acid poisoning due to the third crop's rice decomposition process. In comparison, balanced crop farmers plant high-quality and more expensive rice varieties, which enable them to sell their produce at a higher price; however, their crops have low resistance to diseases and pests (e.g., brown plant hopper and rice blast) (See Appendix 4).

Dike-heightening effects are those effects imposed on rice productivity that create lower profits for farmers in the high-dike areas as compared to the farmers in the nearby low-dike areas. However, this study also discovered that dike heightening have imposed one effect toward the opposite direction—the costs of molluscicide use of the farmers in the low-dike areas. This is due to the water management process associated with high dikes (See Appendix 5). During the third crop (autumn-winter) of each year, the water pumped out of the high-dike areas (about 150,000 ha in An Giang) to nearby low-dike areas (~50,000 ha) carry a significant amount of golden apple snails together with their eggs. Consequently, the higher cost of pesticide use incurred by balanced crop rice farmers were due to the redistribution effect of golden apple snails caused by dike heightening. As a result, pesticide price in Table 1 excluded molluscicides, which are mainly used against the golden apple snails in rice fields.

It was not possible in this study to determine the spillover cost of molluscicide use incurred by balanced crop farmers due to dike heightening. Hence, the author decided to exclude the total costs of molluscicide use from both areas in the analyses (Table 2).

Table 2 shows the comparative analyses of rice production between farmers in the low-dike and high-dike areas in terms of production costs, revenues, and profits from the first two crops (excluding the third crop).

Table 2. Comparative analyses of production costs, revenues, and profits from the first and second crops

Item	High-Dike Area	Low-Dike Area
Including costs of molluscicide		
Revenue ('000 VND/ha/crop)	30,914	37,076
Cost ('000 VND/ha/crop)	16,902	16,947
Profit ('000 VND/ha/crop)	14,011	20,129
Profit ratio (%)	45.32	54.29
Excluding costs of molluscicide		
Cost excluding cost of mollusicide ('000 VND/ha/crop)	16,586	16,537
Profit excluding cost of mollusicide ('000 VND/ha/crop)	14,328	20,539
Profit ratio (%) excluding cost of mollusicide use	46.35	55.40

Note: Calculations do not take into account family labor cost.

Results showed that rice farmers in the low-dike areas profited 1.43 times higher than those farmers in the high-dike areas, and the profit ratio was higher by 8.97%. Although intensive crop farmers spent less per average amount of inputs (except fertilizer and labor wage) yet achieved the same yield as the balanced crop farmers, the former still had lower profits due to the following reasons:

1. The amount of inputs used in the high-dike areas was significantly higher since more seeds, labor days, and amount of pesticides (excluding molluscicides) were used. This may be because intensive crop farmers had to increase their production inputs in order to prevent their yield from decreasing in adapting with the possible impacts of dike-heightening on their farm productivity (as discussed in Section 2.2).
2. The selling prices of the rice varieties produced in the high-dike areas were significantly lower than those in the low-dike areas. As stated previously, this is because intensive crop farmers plant rice varieties that have low commercial value and restricted export market, but have high tolerance to the unfavorable conditions caused by the high dikes.

In terms of the third crop (which is not included in Table 2), the profit from the third crop due to dike heightening was worth VND 15,669,000/ha in 2012. This computation was a straightforward benefit due to dike heightening. This will be further discussed in the CBA calculations in the succeeding sections.

3.2 Impacts of Dike Heightening on Rice Profit

Table 3 shows the coefficients that resulted from the ordinary least squares (OLS) regression of the rice profit model using the translog profit functional form [Equation (4)].The full model was statistically significant at 1% level. The estimated R-squared revealed that 48% of variation in the rice profit was explained.

The author tested the null hypothesis that the joint estimated parameters in Equation (5) are 0. Based on the results of the F-test, the null hypothesis was rejected 5% level of significance, which supported the use of the translog functional form in this study.

Table 3. OLS regression of the rice profit function

Variables	Coefficient	Robust Standard Error
ln(normalized price of fertilizer)	0.089	0.239
ln(normalized price of labor wage)	–0.162*	0.096
ln(normalized price of machine power)	–0.660***	0.179
ln(normalized price of seed)	–0.330**	0.162
ln(normalized price of pesticide)	–0.144	0.128
1/2ln(normalized price of fertilizer)^2	0.917	1.058
1/2ln(normalized price of labor wage)^2	0.373*	0.220
1/2ln(normalized price of machine power)^2	–1.685**	0.735
1/2ln(normalized price of seed)^2	–0.232	0.514
1/2ln(normalized price of pesticide)^2	–0.755**	0.342
ln(normalized price of fertilizer)xln(normalized price of labor wage)	0.066	0.474
ln(normalized price of fertilizer)xln(normalized price of machine power)	–1.019	0.717
ln(normalized price of fertilizer)xln(normalized price of seed)	0.267	0.452
ln(normalized price of fertilizer)xln(normalized price of pesticide)	0.003	0.505
ln(normalized price of labor wage)xln(normalized price of machine power)	0.028	0.435
ln(normalized price of labor wage)xln(normalized price of seed)	0.031	0.264
ln(normalized price of labor wage)xln(normalized price of pesticide)	–0.105	0.206
ln(normalized price of machine power)xln(normalized price of seed)	0.044	0.436
ln(normalized price of machine power)xln(normalized price of pesticide)	0.574	0.523

Table 3 continued

Variables	Coefficient	Robust Standard Error
ln(normalized price of seed)xln(normalized price of pesticide)	–0.229	0.262
ln(normalized price of fertilizer)xln(land cultivated area)	0.184	0.288
ln(normalized price of fertilizer)xln(number of working age labor)	0.108	0.367
ln(normalized price of labor wage)xln(land cultivated area)	0.239	0.170
ln(normalized price of labor wage)xln(number of working age labor)	–0.061	0.222
ln(normalized price of machine power)xln(land cultivated area)	0.388	0.310
ln(normalized price of machine power)xln(number of working age labor)	–0.023	0.291
ln(normalized price of seed)xln(land cultivated area)	0.177	0.239
ln(normalized price of seed) xln(number of working age labor)	0.160	0.287
ln(normalized price of pesticide)xln(land cultivated area)	–0.005	0.133
ln(normalized price of pesticide)xln(number of working age labor)	0.204	0.200
ln(land cultivated area)	–0.017	0.054
ln(number of working age labor)	0.025	0.075
1/2ln(land cultivated area)^2	0.019	0.093
1/2ln(number of working age labor)^2	0.151	0.251
ln(land cultivated area)xln(number of working age labor)	0.055	0.099
Age	–0.006*	0.003
Gender	–0.003	0.128
Education	–0.014	0.011
Training	0.124	0.081
Soil Rank	0.226**	0.105
Disease	–0.090	0.066
Off farmrate	–0.251	0.255
Dikeheightening	–0.243*	0.133
Constant	1.596***	0.264
R-squared	0.480	
Included observation	190	

Notes: ***, **, * indicate statistical significance levels at the 1%, 5%, and 10%, respectively.

For models that include variables that are nonlinear or have interactive functions of other variables, multicollinearity can be a problem. To avoid multicollinearity, the original variables were centered before the other variables were computed from them (Jaccard and Turrisi 2003). The mean of the centered variable was then zero (the standard deviation stayed the same). The estimate of the profit function using centered variables showed the absence of multicollinearity (the correlations of independent variables were less than 70%).

However, the estimate of the profit function showed the existence of heteroskedasticity. The results of the Breusch-Pagan test rejected the null hypothesis of homoscedasticity at 1% significance level. Therefore, the author used the procedure called the heteroskedasticity-robust inference in order to adjust standard errors, *t*, *F*, to make them valid in the presence of hetereskedasticity (Gujarati 2003) (Table 3).

The coefficient of the dike-heightening variable (which represented the effect of dike heightening) was negative ($P < 0.1$). This confirmed that dike heightening reduced the profit of rice production in the high-dike areas. The reduction in rice profit can be calculated using the coefficient presented in Table 3. The estimated profit from intensive cropping, after the influences of other factors were eliminated, was approximately VND 14,075,000, and about VND 17,949,000 from balanced cropping. The decrease in profit due to dike heightening can be estimated by getting the difference between the profits gained from intensive cropping and that from balanced cropping. The decrease in profit was calculated to be VND 3,874,000/ha per crop (i.e., first and second crops) or VND 7,748,000/ha per year—a percentage reduction of 21.6%. This was the profit loss incurred by rice farmers in the high-dike areas in 2012, after 10 years of heightening dikes and planting three rice crops continuously.

The analysis assumed that the profit lost by intensive crop farmers have accumulated over the past 10 years at a constant rate. Hence, a 10-year cumulative loss of 21.6% implies a profit reduction rate of 2.3% per year for each crop. Accordingly, the author provisionally assumed declining time trends for rice production at 2.3% profit per year for the15-year benefit period starting from 2012. As mentioned previously, there are environmental problems that are cumulative over time; thus, the rice profit estimated in this study would likely further decline cumulatively. The author also showed that cost-benefit conclusions were insensitive to this assumed rate of profit decline, as will be discussed later in the sensitivity analysis (Section 3.4.5).

The model also showed that with $P < 0.1$, the farmer's age may explain the variations in profit. The effect of age on profitability may be due to the notion that older farmers tend to be less efficient than the younger ones.

Meanwhile, the effect of soil quality was significantly different between the low-dike and high-dike areas; it was also an important factor that affected profit ($P < 0.01$).

3.3 Impacts of Dike Heightening on the External Costs of Pesticide Use

In this study, the estimates of the external costs associated with pesticide use were likely to be conservative due to the following reasons:

1. These estimates represented only the increase in external costs of pesticide use due to the increase in crop intensity. As stated in Section 2.2.2 regarding the weakness of PEA, the estimates derived did not capture the important relationship between dike heightening and the risk exposure due to pesticide use.
2. In estimating the external costs of pesticide use in this study, the author was not able to account for a significant number of the active ingredients present in the pesticides used by the farmers. This was because these active ingredients were not in the database of eco-toxicological effects. Accordingly, the author was not able to compute for the EIQ of these missing active ingredients, which was an essential input for calculating the PEA (Table 4).

Table 4. Number of active ingredients (types) and percentage of active ingredients (%) obtained, environmental impact quotient (EIQ), and external cost (EC), by crop, by cropping system

Crop	Number of Active Ingredients (Types)			Number of Active Ingredients Obtained EIQ and EC (%)	
	High Dike	Low Dike	Low Dike/ High Dike (%)	High Dike	Low Dike
First crop	95	64	67.37	53.68	59.38
Second crop	93	63	67.74	53.76	63.49
Third crop	94	–	–	53.19	–

Table 4 shows that the number of active ingredients in the low-dike areas was significantly lower than those in the high-dike areas (33% lower).

As stated in Section 2.2.2, the existence of the increase in pesticide-use external costs in the first and second crops could not be tested. Instead, the author tested for the existence of the increase in the amount of active ingredients in the pesticides used by farmers. The amount of active ingredients was also significantly lower in the low-dike area for both the first and second crops (if molluscicides are not considered) as compared to that in high-dike area, which implies that the external costs of pesticide use did increase (Table 5).

Table 5. Average volume, environmental impact, and external cost of pesticide use, by crop, by cropping system

Crop		Amount of AI (kg/ha)		Amount of AI (kg/ha) Excluding Molluscicides		EIQ (average field-use rating/ha)		EC ('000 VND/ha)	
		High Dike	Low Dike	High Dike	Low Dike	High Dike	Low Dike	High Dike	Low Dike
First crop	Mean SD	4.81^{a} 3.21	7.50^{b} 5.43	3.29^{a} 2.31	2.58^{b} 1.36	36.904 34.056	35.721 57.091	148	122
Second crop	Mean SD	4.86^{a} 3.22	7.67^{b} 5.43	3.31^{a} 2.31	2.50^{b} 1.12	38.028 34.891	36.069 56.971	155	124
Third crop	Mean SD	4.97 3.20	N/A	3.28 2.34	N/A	37.197 34.960	N/A	151	N/A

Notes: (1) Means that do not share the same subscript letter are significantly different ($P < 0.05$); (2) AI = active ingredients; SD = standard deviation; N/A = not applicable.

Based on the calculation illustrated in Appendix 1, the EIQs of the first and second crops in the high-dike area were not significantly higher than those in the low-dike area (Table 5). However, this may be due to the higher percentages of those "missing" ingredients in the pesticides used in the high-dike areas. Nevertheless, the results can be summarized as follows:

1. The external costs of pesticide use in the first and second crops in the high-dike areas were higher by VND 22,000/ha and VND 31,000/ha, respectively, as compared to those in the low-dike areas.
2. The external costs of pesticide use in the third crop enabled by the high dikes was VND 151,000/ha.
3. In total, the increase in the external costs of pesticide use in 2012 due to dike heightening was VND 204,000/ha.

3.4 Estimation of Benefits and Costs

In estimating the benefits and costs of dike heightening, the author used the following assumptions and tools to calculate their present values: (1) discount rate of 3%, (2) dike lifespan of 15 years, and (3) GDP deflator provided by the World Bank (World Bank 2013a).

3.4.1 Estimation of benefits

This subsection discusses the calculation of the present value of the extra benefits due to dike heightening over the 15-year lifespan of high dikes. The resulting estimates equates to the present value of the profits gained from 15 third crops that have been and would have been possible due to the high dikes from 2012–2026.

As previously discussed, the primary benefit of dike heightening is the profits gained from the third crop. Based on the survey data, the profit gained in 2012 from the third crop was VND 15,669,000/ha, excluding the cost of family labor.

Rice production is labor intensive. Hence, if the cost of family labor (at current market prices) was considered in the calculation, then labor cost would be around VND 5,141,000 per crop per year. This would account for about one-third of the estimated profit. There is a need to take into account the costs of family labor so as not to overestimate the actual benefit of dike heightening. To be conservative, the author valued the cost of family labor at half the market price. The estimated profit of the third crop in 2012 then decreased to VND 13,099,000/ha.

Through the course of the 15-year lifespan of the high dike, the author assumed that the profit gained from the third crop would be subject to a cumulative loss of 2.3% per year. This assumption was based on the discussion in Section 3.2 regarding the impact of dike heightening on rice profitability.

Accordingly, the present value of the extra benefits due to dike heightening over 15 years was calculated to be VND 139,311,000/ha or USD 6,689/ha.

3.4.2 Estimation of costs

This section details the present value of the extra costs due to dike heightening over the 15-year lifespan of the high dikes. These extra costs included the following:

1. decrease in profit gained from the first and second crops in the high-dike areas as discussed in Section 3.2,
2. increase in pesticide-use external costs as calculated in Section 3.3,
3. foregone revenues from floodplain fishery due to the loss of floodplain area for fishing during flood season, and
4. the increase in infrastructure costs due to dike heightening.

Present value of the decrease in profit from first and second crops. As stated in Section 3.2, the author assumed that intensive crop farmers would further lose profits from the first and second crops at the rate of 2.3% per annum for the period 2012–2026 due to dike-heightening impacts. The profit loss from the first and second crops in 2012 was estimated to be VND 7,748,000/ha. Accordingly, the present value of the decrease in profits from the first and second crops in the high-dike area due to dike heightening was estimated to be VND 101,626,000/ha (USD 4,879/ha) over the 15-year period.

Present value of the increase in pesticide-use external costs. In Section 3.3, it was estimated that the increase in the external costs of pesticide-use in 2012 due to dike heightening was VND 204,000/ha. Over the 15-year lifespan of the high dike starting from 2012, the external costs of pesticide use in the high-dike areas were likely to increase further overtime. This was based on the fact that the amounts and number of active ingredients in the pesticides used in intensive cropping were significantly higher than those in balanced cropping after farmers in the high-dike areas have continuously followed the three-rice-cropping system for the past 10 years. However, for simplicity, the author assumed that the external costs of pesticide use in the high-dike areas would no longer increase over the 15-year lifespan of the high dike. The resulting present value of the increase in pesticide-use external costs over the 15-year period was then calculated to be VND 2,508,000/ha or USD 120/ha.

Present value of foregone revenues from floodplain fishery. The value of revenue loss per hectare per year from losing the natural fish habitat in the floodplain (i.e., flooded rice field) due to dike heightening was equivalent to the foregone revenues from floodplain fishery per hectare due to dike heightening.

The first stage of the calculation involved estimating the foregone revenues from floodplain fishery for the period 2001–2012 (i.e., construction period). This was done by estimating the volume of fish in the rice field that would have been harvested if the high dike was not built at all in 2001. To calculate this, the author made the following assumptions:

1. Based on the survey conducted by De Graaf and Chinh (2003), the average fish yield in the floodplains in the southern provinces of Vietnam in 1995 was 119 kilograms per hectare (kg/ha).
2. Le (2008) reported a significant increase in fish yield from 1995 to 2001 in the Mekong Delta due to technological developments in the fishery sector (i.e., development and application of new fishing gear), although this had led to greater damages to natural aquatic resources. The author of the present study applied the 1995–2001 rate of increase in the volume for all captured fish in general (including those from rice fields, canals and rivers) obtained from the 2006 Statistical Yearbook of the An Giang General Statistics Office (AGGSO 2006) to adjust the projection of fish yield in 2001 for captured fish in the rice

field. Accordingly, the volume of fish in the rice field that would have been harvested in 2001 would be 40% higher than those in 1995 or would be 168 kg/ha in 2001.

3. In the surveys conducted by Le (1995) and Le and Nguyen (2000), an average 10%–13% annual decline in fish harvest from rice fields was reported before dike heightening. The author of the present study then assumed that fish harvest from rice fields at the study sites would have declined by 11.5% per year from 2001 to 2012 if the high dike was not constructed during the period.
4. During the construction period of the high dike, this study used the value (in tons) of fish catch based on the current prices (for each year) calculated by AGGSO (AGGSO 2006; AGGSO 2010; AGGSO 2011; AGGSO 2012).

Based on these assumptions, the total foregone revenues from floodplain fishery due to the construction of the high dikes amounted to VND 21,169,000/ha for the whole 2001–2012 period (Table 6).

The second stage of the estimation involved calculating the foregone revenues from floodplain fishery due to dike heightening during the benefit period (i.e., 2013–2026).[3] In estimating the value of fishery over the 15-year lifespan of the high dike, the author speculated on the value of captured fish from the rice field that would be lost due to the construction of the high dikes. A number of issues had to be considered as follows:

1. The fish being harvested from the Mekong Delta, specifically in the Lower Mekong Basin, are expected to decline in the foreseeable future; that trend is a scenario up to 2030. The reasons for the declining trend are due to overfishing, water pollution, destruction of natural fish habitats within the delta, and the increased pressures from the upstream countries (Chen and Zhang 2011). The author then applied the same 11.5% decline rate used in estimating the fish catch during the construction period in order to estimate the same during the benefit period 2013–2026.

2. The domestic demand of fish is expected to increase rapidly in the same scenario up to 2030 due to population growth and increase in real incomes (Chen and Zhang 2011). Thus, fish prices are likely to increase continuously during the period 2012–2026. However, the author decided to exclude this consideration as there is no concrete indication as to how much fish prices could increase for the period in study. Therefore, the author assumed that fish prices from 2013 to 2026 would be the same all throughout the period, and the same assumption was applied with regard to the price of fishery catch in 2012. The value of fish catch was then pegged at 2012 prices, which was VND 32.91 million per ton.

Based on these considerations, the total present value of foregone revenues from floodplain fishery for the period 2013–2016 was estimated to be VND 7,750,000/ha. In total, the present value of foregone revenues from fishery due to dike heightening was estimated to be VND 29,919,000/ha (USD 1,436/ha), 74.1% of which would be lost during the construction period.

Present value of the increase in construction costs. As the low dikes had been converted into high dikes, the construction costs of high dikes were equivalent to the construction costs of dike heightening. The high-dike system in An Giang province consisted of a series of high dikes with their associated structures (e.g., pumping stations, etc.). These were built gradually each year "one piece at a time" during the construction period (Table 7). The present value of the construction costs that were incurred from 2001 to 2012 was then estimated to be VND 29,489,000/ha (USD 1,416/ha).

Present value of the increase in maintenance costs. Meanwhile, the data on maintenance costs during the construction phase were not available and were then excluded in this study. Therefore, the increase in maintenance costs of dike heightening were estimated as the difference between the maintenance costs of high dikes versus low dikes during the benefit period only (i.e., 2012–2016). Although the dike systems at the study sites were made of mud/earth, the annual maintenance costs were expected to keep the dikes fully operational for 15 years. Based on the available data from the irrigation department, the maintenance costs in 2012 for the high-dike system in the 150,000-hectare area used for the third crop in An Giang were estimated at VND 194 billion or VND 1,297,000/ha.

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[3] Year 2012 was not included because it was already included in the construction phase.

Table 6. Value of foregone revenues from floodplain fishery during construction period of (2001–2012)

Year	Loss of Fish Yield from Floodplain Fishery (kg/ha) (1)	Value of Fishery Catch ('000 thousand VND/t) at current prices (2)	Revenue Loss per hectare ('000 VND/ha) (3) = (1)*(2)*1,000	GDP Deflator	Revenue Loss from Floodplain Fishery ('000 VND/ha) at 2012 prices	Present Value ('000 VND/ha) r = 3%
2001	168	3.81	640	43	2,002	2,771
2002	149	3.73	555	45	1,654	2,223
2003	132	5.39	709	48	1,979	2,582
2004	116	5.67	660	53	1,685	2,135
2005	103	5.58	575	58	1,345	1,654
2006	91	5.94	542	63	1,166	1,392
2007	81	8.75	706	69	1,387	1,608
2008	71	11.94	853	84	1,366	1,537
2009	63	12.51	791	89	1,193	1,303
2010	56	21.46	1,201	100	1,615	1,713
2011	50	31.98	1,584	121	1,756	1,809
2012	44	32.91	1,442	135	1,442	1,442
					Total	**22,169**

Note: r = discount rate

Table 7. Consolidated list of construction works of dike system, An Giang province, 2001–2012

Year	Total Works	Number by Structure					Total Length (m)	Dug and Embanked Amount (m^3)	Area for Third Rice Crop (ha)	Total Costs (in million VND) (2012 prices)
		Canal	Dike	Culvert	Pumping Station	Field Internal Irrigation				
2001	711	57	286	347	21		1,789,906	11,735,233	18,855	800,674
2002	555	103	149	230	73		1,316,545	6,614,596	35,352	397,130
2003	766	142	234	385	5		1,003,931	9,721,564	62,998	492,992
2004	793	126	125	297	79	166	733,857	4,561,001	80,340	267,175
2005	501	194	107	163	37		879,879	4,418,332	83,385	115,483
2006	548	126	18	140	100	164	606,819	3,135,941	43,152	67,106
Total Phase 1	3,874	748	919	1,562	315	330	6,330,937	40,186,667	324,082	2,140,560
2007	351	99	32	102	1	117	496,955	3,107,261	58,859	52,058
2008	560	52	57	249	202		331,360	3,660,971	94,421	259,271
2009	673	166	24	206	277		553,940	5,647,703	84,249	323,387
2010	485	148	238	0	99		949,564	8,774,792	115,037	246,998
2011	948	324	425	0	199		1,151,000	7,880,000	133,723	361,003
2012	549	51	244	78	176		614,800	4,963,500	149,542	238,122
Total Phase 2	3,566	840	1,020	635	954	117	4,097,619	34,034,227	635,831	1,480,839
TOTAL	**7,440**	**1,588**	**1,939**	**2,197**	**1,269**	**447**	**10,428,556**	**74,220,894**	**959,913**	**3,621,400**

Source: An Giang Sub-Department of Irrigation (AGSDI 2013)

Notes: (1) Total expenses are adjusted to 2012 prices using GDP deflators (World Bank 2013a); (2) Total costs included the costs of building temporary dam in 2001 (VND 1.49 billion)

For the low-dike area, the maintenance costs in 2012 varied from upstream to downstream. After the annual flood season in 2011, about VND 2–3 billion were used to maintain the low-dike system in the 10,000-hectare upstream area. This equates to an average of VND 200,000/ha. Meanwhile, maintenance cost in 2012 in the 40,000-hectare downstream area amounted to VND 2 billion (VND 50,000/ha). In this case study where dike heightening is mainly located downstream, the author used the costs associated with low dikes in the downstream area to calculate the increase in maintenance cost of dike heightening. The difference in the maintenance costs of high dikes and low dikes in 2012 was therefore VND 1,247,000/ha. This also translates to the increase in maintenance cost due to dike heightening.

The author also assumed that during the 15-year lifespan of the high dike, the maintenance costs for each year would remain the same. Therefore, the present value of the increase in maintenance costs over the 15-year lifespan of the high dike was calculated to be VND 15,333,000/ha (USD 736/ha).

Present value of the increase in management costs. Along with rapid investment and development of high dikes, the local government of An Giang province also established a management machinery of irrigation system or high-dike system at all administrative levels. Dikes are classified into five levels based on the population protected by the infrastructure, the importance level of defense, security, socioeconomics, flood and storm characteristics of each region, areas and administrative boundary, average flood depth of residences compared to flood level designed, and designed flood flow (MARD 2010). Each management level is responsible for managing certain levels of dikes. The management machinery is summarized in Figure 3

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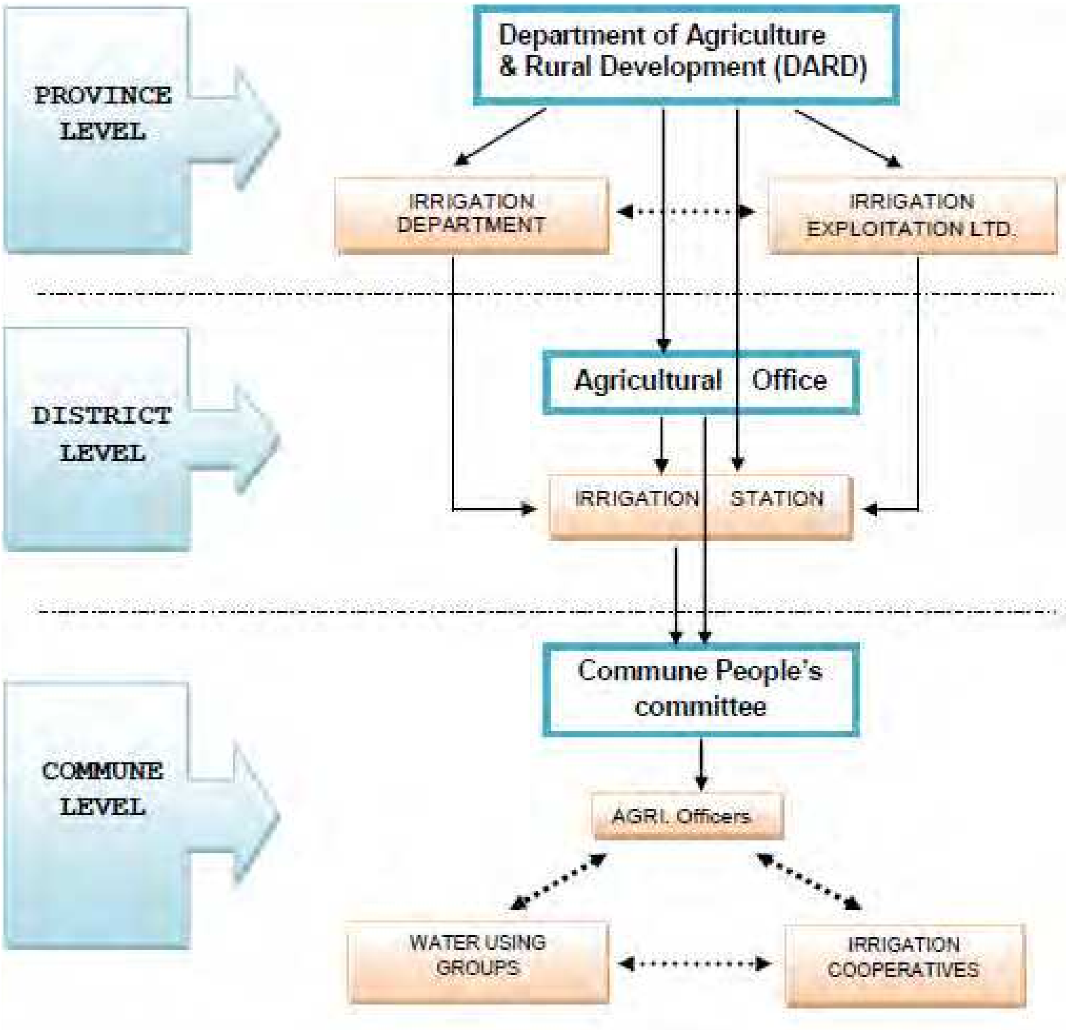

Figure 3. Management machinery of the dike system, An Giang province

Similar to the maintenance costs, the data on the management costs of the high dikes during the construction phase were not available for this study; thus, it was excluded in the analysis. Therefore, the increase in the management costs due to dike heightening was estimated for the benefit period only (i.e., 2012–2016).

In this study, the management costs of high dikes were assumed to be equivalent to that of the low dikes in An Giang. This was because the management machinery of the irrigation system at all administrative levels was established along with (and mainly due to) the rapid investment and development of high dikes. It was not possible in this study to separate the management costs of the high dikes from the low dikes at the study sites. Moreover, the land area of An Giang is mostly composed of high-dike areas (about 75%).

Table 8 shows that the total budget for managing the dike systems in An Giang province in 2012 alone was VND 133.5 billion or VND 667,500/ha. Similar to the calculation of the construction and maintenance costs, the author assumed the same 2012 dike management cost each year for the entire 15-year lifespan of the high dikes. Accordingly, the present value of the management cost for the entire 15-year lifespan of the high dikes was VND 8,201,000/ha or USD 394/ha.

Table 8. Management costs of dike system, An Giang province, 2012

Management Level	Organizations	Province's Budget (million VND)	Budget ('000 VND/ha)	Note
Provincial level	Irrigation Department	1,200	6.0	Lump-sum budget for 15 personnel
	Irrigation Exploitation Ltd.	7,000	35.0	Lump-sum budget for 65 personnel
District level	District office of Agricultural and Rural Development	3,300	16.5	Lump-sum budget for one agriculture personnel in the district agriculture office, and five personnel in an irrigation station per district
	11 Irrigation Stations			
Commune level	Commune level	2,000	10.0	One commune agriculture staff per commune
	300 cooperative-group water users	20,000	100.0	Operation costs
	Support to agriculture infrastructure	100,000	500.0	
Total		**133,500**	**667.5**	

Note: The province's budget to cover the management costs of the dikes covered 200,000 ha of dike area, including 150,000 ha of the three rice cropping and 50,000 ha of the two rice cropping.

3.4.3 CBA of dike heightening from public sector perspective

Table 9 summarizes the CBA results of dike heightening from the perspective of the public sector. From an economic perspective, the net benefits of dike heightening were negative. Society would stand to lose about VND 47.8 million per hectare (USD 2,293/ha) or VND 7,165 billion (USD 344 million) for An Giang province as a whole (Table 9). The results also showed that the decrease in profit from the first and second crops due to dike heightening (VND 101.626 million per hectare) contributed the most in the total cost of dike heightening (54.5%). This was followed by infrastructure cost (VND 53,023,000/ha), and then by the cost due to the foregone revenues from floodplain fishery (VND 29,919,000/ha). The increase in pesticide-use external costs (VND 2,508,000/ha) contributed the least, which accounted for 1.2% out of total estimated costs of dike heightening.

Table 9. Benefits gained by public sector from dike heightening in An Giang, Vietnam

Category	Estimated Values	Present Value ('000 VND/ha)
Benefits	Profit from the third crop in high-dike areas	139,311
Costs	Decrease in profit from the first and second crops	101,626
	Construction costs	29,489
	Maintenance costs	15,333
	Management costs	8,201
	Cost due to foregone revenues from floodplain fishery	29,919
	Increase in external costs of pesticide use	2,508
Total net benefits ('000 VND/ha)		–47,767
Total net benefits (USD/ha)		–2,293
Total net benefits (billion VND/whole province)		–7,165
Total net benefits (million USD/whole province)		–344

Notes: (1) Base year = 2012; (2) Discount rate = 3%

3.4.4 CBA of dike heightening from private sector perspective

This section presents the CBA results of dike heightening from the perspective of a private sector (i.e., the local people) in An Giang province. In this study, the local people refer to the intensive crop farmers, balanced crop farmers, and fishermen. The social costs, which have been omitted here (unlike in the public perspective), included a part of the infrastructure costs and the total increase in pesticide-use external costs.

From the intensive crop farmers' perspective. Within the 15-year lifespan of the high dikes, intensive crop farmers would stand to gain an amount of VND 139,311,000/ha due to the third crop enabled by dike heightening. However, the impact of dike heightening on their first and second crops would cost them VND 101,626,000/ha (Table 10). In addition, they would still have to contribute both labor and money for the construction and maintenance of the high dikes. Based on the 2012 data of An Giang's irrigation department, 30% and 15% of the construction and maintenance costs, respectively, were paid by intensive crop farmers; the remainders of these two costs plus the management cost were shouldered by the central and local government.

Table 10. Benefits gained by private sector from dike heightening in An Giang, Vietnam

Category	Estimated Values	Affected Groups	Present Value ('000 VND/ha)
Benefits	Profit from the third crop in high-dike areas	Intensive crop farmers	139,311
Costs	Decrease in profit from first and second crops	Intensive crop farmers	101,626
	Construction cost	Intensive crop farmers	8,847
	Maintenance cost	Intensive crop farmers	2,300
	Value of foregone revenues from floodplain fishery	Fishers	29,919
Net benefits of intensive crop farmers			26,538
Net benefits of fishers			–29,919
Total net benefits ('000 VND/ha)			–3,381
Total net benefits (USD/ha)			–162
Total net benefits (billion VND/whole province)			–507
Total net benefits (million USD/whole province)			–24

Notes: Base year = 2012; (2) Discount rate = 3%

Accordingly, the present value of the construction and maintenance costs incurred by the intensive crop farmers were VND 8,847,000/ha and VND 2,300,000/ha, respectively. Hence, the actual net benefits that this group would gain from dike heightening would only be VND 26,538,000/ha within the 15-year lifespan of the high dikes (VND 1,769,000/ha per year).This amount is equivalent to only 19% of the intensive crop farmers' profit from the third crop for each year within the 15-year lifespan of the high dikes, and less than 10% of the balanced crop farmers' average profit from each of the first and second crops in 2012. In addition, the results of the analysis suggest that the actual net benefits would turn negative if farmers decide not to grow a third crop since they are still expected to pay all of the dike-related costs similar to what the famers in the high-dike areas do.

Although intensive crop farmers have been able to adapt to some of the impacts of dike heightening (e.g., by increasing inputs, changing rice varieties, etc.), they are still constrained by the increased levels of environmental stress and loss of biodiversity associated with intensive farming. Costs such as these were reflected on more than 20% of the decrease in the intensive crop farmers' profit in year 2012 alone, after 10 years of the dike heightening. These farmers would likely be further constrained over the remaining lifespan of the dike.

This may explain the grassroots problem as to why An Giang rice farmers have perceived themselves as being trapped in poverty despite the hard work they've put in. Although they've worked harder than before, their incomes have remained low. They are even more pressured to get a loan to pay for their rice production costs and other dike-related costs, which have consequently made them more prone to indebtedness and landlessness (Duc 2013).

One of the long-term strategies that rice farmers have thought of (and are likely to adopt) to address this problem is shifting from rice farming to other non-rice production activities. One survey conducted in An Giang and Dong Thap provinces found that 58.8% of the rice farmers' children were working away from home and were not engaged in rice production-related activities (Pham 2015). In addition, the analysis in Section 3.2 have shown that the age variable of rice farmers had a statistically negative effect on rice profit (Table 3)—the older the rice farmers were, the less profit there would be. This may be because in the sample, the average age of rice farmers were 44 years old. At this age, a farmer's failing health would mean less ability to work on the farm. Accordingly, this situation would challenge the sustainability of rice production in the future.

From the perspective of fishers. This group incurred foregone revenues of VND 29,919,000/ha from floodplain fishery due to dike heightening (Table 10), and hence were disadvantaged by dike heightening. Floodplain fishery remains significantly important to the rural folk (rich or poor) in Mekong Delta. They remain important not only to fulltime fishers but also to households, in which fishing has been a component of wider livelihood strategies (Baran et al. 2005). Sjorslev (2001) found that 7% of the households in Mekong Delta were involved in professional fishing, 66% in part-time fishing, and 5.7% in fish processing and trading. In terms of poverty, the wild inland fishery was more important than aquaculture. Poor people tend to become more reliant on wild aquatic resources as a result of growing indebtedness, landlessness, and displacement (Sultana, Vo, and Chiem 2003).

From the perspective of balanced crop farmers. There is evidence that this group incurred spillover costs due to dike heightening such as the cost of molluscicide use. However, the author ignored these costs here. Although it was observed in this study that the contiguous balanced crop farmers had substantially high application rate of molluscicides, it was not possible to ascertain how much of this amount was for reducing the spillovers from the intensive cropping site.

From the perspective of general community. With regard to the increase in the external costs of pesticide use that were calculated in this study, the payment for these costs varied according to the community's distance to the rice fields; still, it was the general community who suffered. Rice farmers are expected to suffer the most and pay the most since they are the direct rice "applicators," "pickers," and "consumers" as categorized by the EIQ system. However, these external costs are not well recognized, and it was not clear to the author as to how the precise amount that the general community paid could be determined. Therefore, private costs might not include these external costs.

As can be seen in Table 10, the private net benefits of dike heightening are negative. This result indicates the economic inefficiency of the dike-heightening project at the local scale.

The profit gained from the third crop—a benefit of dike heightening—is well-recognized. However, the decrease in profits from the first and second crops in the high-dike areas is not well known; and this study was the first that attempted to determine such.

Although the construction, maintenance, and management costs in this study were calculated in a straightforward manner, the research team needed time and a very good network to access, collect, and synthesize the required secondary data on those costs. Thus, such data have not been accessed or recognized so far.

Also, floodplain fishery in VMD is exceptionally important to the region and the whole country. However, Vietnam considers only the value of the Mekong waters for irrigating the rice fields and as a way to oppose saline intrusion (Baran et al. 2005). As a result, there is no official report that recognizes the foregone revenues from floodplain fishery as a cost of dike heightening.

Based on Table 10, when the foregone revenues from floodplain fishery, the decrease in profit from the first and second crops in high-dike areas, and the high dike-related fees are subtracted from the benefits, the local people in the high-dike areas at the study site lost about VND 3,381,000/ha in 2012 due to dike heightening.

3.4.5 Sensitivity Analysis

Changes in discount rates. The first part of the sensitivity analysis involved evaluating the CBA results at different discount levels. Table 11 shows the CBA estimates, both from the public and private sectors' perspectives, at different discount rate levels.

Table 11. CBA calculation at discount rates 3%, 6%, and 10%, public and private perspectives

Discount Rate	Category	Benefits (PV '000 VND/ha)	Costs (PV '000 VND/ha)	Net Benefits (PV '000 VND/ha)
3%	Public perspective	139,311	187,078	–47,767
	Private perspective	139,311	142,692	–3,381
6%	Public perspective	118,051	176,413	–58,362
	Private perspective	118,051	131,151	–13,101
10%	Public perspective	97,364	174,702	–77,338
	Private perspective	97,364	124,846	–27,482

Note: PV = present value

Table 11 shows that as the discount rate for a CBA estimate increases, the present values of the benefits or costs spent in the past also increase; whereas the present values of the future benefits or costs decrease. In this CBA calculation, the benefits would occur mainly in the future (i.e., 2012–2026), whereas a significant amount of the costs (construction costs, foregone fish revenues) were spent in the past (i.e. 2001–2012). As a result, both the public and private net benefits of dike heightening are still negative and even further decrease at discount rates of 6% and 10%, as compared to those at 3%. This result confirmed the economic inefficiency of dike heightening regardless of the discount rates.

Changes in reduction rate of rice profits. The sensitivity of the CBA results was also assessed by assuming that there was no decline in rice productivity (Table 12). This means that profit would not further decline over the lifespan of dike. These results were also provided at different discount rates.

Table12. CBA calculation using the new annual profit reduction rate, at discount rates 3%, 6%, 10%, public and private perspectives

Discount Rate	Category	Benefits (PV ‘000 VND/ha)	Costs (PV ‘000 VND/ha)	Net benefits (PV ‘000 VND/ha)
3%	Public perspective	161,066	180,900	–19,834
	Private perspective	161,066	136,514	25,552
6%	Public perspective	134,854	171,403	–36,549
	Private perspective	134,854	126,141	8,713
10%	Public perspective	109,595	171,845	–62,250
	Private perspective	109,595	121,989	–12,394

Note: PV = present value

With this new assumption, the social net benefits remained negative regardless of the discount rates. This confirms the conclusion that dike heightening is not sensitive to the assumption of sustained rice productivity decline.

Conversely, the private net benefits were sensitive to the change in profit reduction rate as they turned positive at 3% and 6% discount rates (Table 12). At 3% and 6% discount levels, net benefits were VND 25,552,000/ha and VND 8,713,000/ha, respectively, during the dike’s lifespan. As mentioned previously, those amounts would be the actual benefits that the local people would gain assuming that they would be able to cultivate 15 additional third crops for the entire 15-year lifespan of the high dikes. However, the resulting private net benefits were equivalent to 6.5% –15% of the third crop’s profit only. At 10%, the private net benefits remained negative.

This result confirms that dike heightening is privately unattractive at high discount rates and yields very low profits at low discounts rates. The realistic discount rate is closer to 10%, rather than 3% or 6%; thus, the indication that private net benefits lean toward the negative value is strong**.**

3.5 Benefits and Costs Not Estimated in the Study

3.5.1 Trade-off between the reduction in flood damages due to low-dike overtopping and the increase in flood damages due to high-dike breaching

The following discussion explains the trade-off between the benefit of dike heightening (i.e., reduction flood damages) and the cost of dike heightening (i.e., flood damages that occur when a high dike breaks or when there are severe floods). Although this study did not calculate the benefits of dike heightening in reducing flood damages due to overtopping low dikes, this study still maintains that the CBA results were conservative because the damage costs that may occur if the high dike breaks were not included in the analysis.

Aside from the third crop enabled by dike heightening in the VMD floodplain, another important benefit of dike heightening is the reduction in the damages caused by flooding, especially damages to crops. The high dikes in the VMD floodplain ensure that farmers are able to secure the production of the second crop (summer-autumn crop), which the low dikes could not ensure. Before the high dikes were built, there had been seasons in which the main floods had been high and had come early. The floodwater had been overtopping the low dikes, consequently damaging the second crop during the harvesting phase. In the high-dike system, it is the third crop (autumn-winter crop) which may be exposed to damages caused by dikes breaching. A high-dike system may break due to the pressure created by the main flood peak, exaggerated by heavy rainfall in September and October (the two heaviest rainy months of the year).

Dr. Duong Van Ni of the College of Environment and Natural Resource, Can Tho University warned that the risk of dike breaching has never disappeared with dike heightening, but has accumulated over the years instead (Duong n.d.). The levels of land and river bottom outside the high dikes become increasingly higher due to the sediment deposits, and this leads to higher flood levels and higher probability that the dike will break anytime in the future. The damage costs associated with dike breaching would be very high as the people could lose everything that they have worked for over the years.

The possibility of a big loss due to dike breaching was illustrated in An Giang during the major flooding in 2011. Before 2011, the local people and the government of An Giang had seven continuous years of low to average flood levels; thus, they saw little need to upgrade and consolidate the dikes. When a flashflood occurred in the floodplain, the local people didn't have enough time to react in order to prevent or minimize the flood damages. The floodwater had overflowed the dikes and then penetrated the dike body, consequently causing the dikes to break (AGCFSC 2011). Note that the 4.86-meter peak of the 2011 flood year at Tan Chau on September 30th was lower than that in 2000 (5.06 m), which was used as a reference level to build high-dike systems (AGSDI 2009). Nevertheless, the 2011 flood negatively affected An Giang's agriculture. Aside from the hundreds of thousands of people mobilized to work on shifting schedules (with no payment given to the workers) to save the dikes, the damage cost amounted to VND 72.4 billion (AGCFSC 2011). Using the deflator adjustment, the damage cost at 2012 prices was VND 80.8 billion or VND 404,000/ha (including both the high-dike and low-dike areas of 200,000 ha).

Despite the huge budget spent to construct the high dikes in order to protect the third crop, and despite great efforts and human resources spent to maintain the dikes, losses and damages to the third crop cannot be avoided. The agriculture-related flood losses in 2011 showed more kinds of damages aside from the damages to the third crop, as compared to those in 2000 (Table 13). This may be because the false security created by high dikes weakened the adaptive capacity of the people in the high-dike areas; when in fact, the risks associated with dike systems have not been reduced but have just been transformed due to dike heightening.

Table 13. Agriculture-related flood losses, 2000 and 2011

No.	Loss	Unit	2000	2011
1	Completely re-sowing area (third crop)	ha		4,059
2	Partly re-sowing area (third crop)	ha		500
3	Areas requiring drainage pumping (third crop)	ha		131,000
4	Loss of rice + upland crop	ha	4,947	4,539
5	Flooded third crop rice crop + upland crop	ha		1,261
6	Early harvesting second rice crop + upland crop	ha	16,911	78
7	Loss of fish production	ton	2,478	72
8	Loss of breeding fish	million		5
9	Pond flooded	pond		701
10	Completely lost fruit tree area	ha		24
11	Flooded husbandry facilities	facilities		675
12	Broken dikes by flood	km	1,500	1,000
13	Road flooded	km	193	31
14	Rural road flooded	km	1,069	144
15	Road broken	km		61
16	Land eroded	m^2	363,737	30,803

Source: AGPC (2011)

Due to the 2011 flooding incident, more than VND 688 billion of emergency aid fund was released by the government to protect the 140,000-hectare plantation area allotted for the third rice crop and to compensate for the losses in agricultural production. The costs of consolidating the 1,050-kilometer high-dike systems for protecting the third crop alone were more than VND 280 billion (AGPC 2011). Using the deflator adjustment, this aid translates to VND 5,483,000/ha at 2012 prices.

If only the direct costs of controlling the flood when the dike broke in 2001 and the required aids were considered in the calculation, the cost of the broken dike during the 2011 flooding would amount to VND 5,887,000/ha (at 2012 prices).

As Sparks (1995) noted, if high levees are maintained, then the floodplain cannot fulfill its hydrologic function of conveying and storing major floods; thus, flood damages increase elsewhere. Some of these costs are reflected in the following section.

3.5.2 Benefits and costs not estimated in the study

This study estimated only the total net benefits based on the current available data; some important values were not quantified, which include the following:

1. The reduction in flood damages due to breaking or overtopping low dikes, particularly damages to the second crop; and
2. The benefit of using high dikes as the roads for transportation.

Meanwhile, the costs that were not considered in the study include the following:

1. Damage costs due to high-dike breaching, particularly the damages to the third crop;
2. Increase in external costs of fertilizer use;
3. Increase in flood damages by displacing the flood in downstream areas;
4. Decrease in water retention capacity and groundwater recharge;
5. Increase in duration and extent of saline intrusion in the lower delta during dry season;
6. Increase in dredging costs caused by deposition in the canals and estuaries; and
7. Increase in maintenance cost caused by the increase in flow velocity and collapse of river banks.

All of these costs point toward an even greater level of social cost due to dike heightening, and would seem substantial relative to the benefits that have not been considered.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This study determined the impacts of dike heightening on the VMD floodplain using the cost-benefit analysis (CBA). The "low-dike system" was used as the base scenario to allow the author to compute the differentials between low-dike and high-dike values. It was assumed that high dikes would have a lifespan of 15 years. In order to collect the needed data for calculating the costs of dike heightening on rice productivity and on pesticide-use externalities, the study team conducted surveys among rice farmers in the high-dike and nearby low-dike areas, with the assumption that these areas used to have the same natural and social conditions before dike heightening. In order to estimate the decrease in profit from agriculture production due to dike heightening, a dike-heightening dummy variable was introduced into the rice profit function. The pesticide environmental accounting (PEA) methodology was applied to calculate the increase in external cost of pesticide use.

Results showed that costs due to dike heightening are imposed on both intensive and balanced crop farmers in the study sites. For example, the water management system in high dikes transfers the golden apple snails from the high-dike to the low-dike areas.

The CBA results also showed that the decrease in profit from the first and second crops was the main cost of dike heightening. The second and third largest costs were infrastructure cost and the foregone revenues from floodplain fishery. Except for the infrastructure costs—which were straightforward and well recognized—these two important costs are largely ignored and are not mentioned in official reports related to high dikes. The increase in pesticide-use external cost was the smallest cost out of total estimated costs of dike heightening; likewise, this cost was not significant. Based on the net present value (NPV) decision rule, the results of this study imply that dike heightening do not yield positive net economic benefits from the perspectives of both the public and private sectors. With regard to the perspectives of each group as local people, intensive crop farmers yield a very low positive net benefit from cultivating the third crop enabled by dike heightening. Meanwhile, fishers, balanced crop farmers, and the local people in general are disadvantaged by dike heightening.

The sensitivity analyses showed that the NPVs of dike heightening were not sensitive to the changes in discount rate. Also, applying the assumption of “no further reduction” in rice profits over the dike’s 15-year lifespan, the CBA results from the public perspective did not change; whereas those from the private perspective changed at 3% and 6% discount rates. However, at 3% and 6% discount rates, the net economic benefits that would be gained from planting the additional third crop until 2026 were positive but very low.

4.2 Recommendations

Dike heightening in the floodplain as an infrastructure response to support rice intensification is not advisable. The impacts of dike heightening are both direct and indirect and may be both for short-and long-term. The direct impacts (usually short-term) can be easily seen and are easier to comprehend. However, many of the indirect (usually long-term) environmental effects of dike heightening are cumulative and involve changes in ecological processes that may not be well understood. Yet, these long-term effects that signal deteriorating ecosystems have far more important implications than those effects that can be easily be observed. For example, this study calculated the decrease in intensive crop farmers’ profits from the first and second crops due to dike heightening to be more than half of the total cost of dike heightening. Thus, dike-heightening projects should no longer be pursued in VMD.

In connection with this, the government should limit the negative impacts of dike heightening by improving the design and management of the existing high dikes such that the structure would allow floodwater to flow into the floodplain. The intended design of the high dikes in VMD from the beginning allows the flood to come every two years into the high dikes. However, this was not implemented due to improper design and management failures. In the course of conducting the survey, the study team recognized that local farmers and authorities have been increasingly becoming aware of the need to allow the flood to flow naturally. This helps improve soil quality in the fields and helps release some of the environmental stress placed by the cumulative effects of numerous human activities (e.g., increased agro-chemical pollution inside high dikes). However, implementing these changes would be challenging—the local people have already adapted to the permanent “no-flood” condition inside the high dikes. Thus, to allow flooding would entail new costs.

Intensive crop farmers are the primary beneficiaries of the dike-heightening project. This study found out that intensive crop farmers in VMD have adapted to the negative impacts of dike heightening by changing some of their farming practices such as increasing farm inputs and planting other rice varieties. However, considering that rice prices “are not high but are very unstable in the market” and that they “experience the worst effects of price fluctuations” (Tran, Do, and Le 2013, p. 9), intensive cropping would more than likely increase the risks faced by rice farmers.

As shown in the CBA results of this study, dike heightening may establish a feedback loop of perpetual reliance on costly dikes and agro-chemicals, and continuing environmental and ecological degradation. Rice farmers suffer the most from this as they are forced to work harder yet be less productive and profitable. They cannot revert to the integrated rice-natural fish farming system, which is now made impossible due to the high dikes. They are also constrained from shifting to other diverse systems that use lesser amounts of agro-chemicals; these systems would be ineffective in the face of the unfavorable conditions (due to the increased levels of environmental stress and reduced biodiversity caused by dike heightening) in the high-dike areas.

Balanced crop farmers near the high dikes have also been imposed with the costs of dike heightening. Those areas with balanced cropping—which have thus far remained unchanged—have also been affected by the increasing environmental stress and have been exposed to the risks associated with the externalities of intensive cropping. For example, in the context of the intensive rice production supported by the government, by heightening dikes, increased production costs means that it may be more economically rational for the balanced crop farmer to follow the adaptation farm practices paved by the intensive crop farmers. However, similar to the latter’s experience at the study sites, changing farm practices in order to maintain the quantity of harvest at the cost of its quality may result in lower profit per crop for balanced crop farmers. In addition, if farmers have less incentive to follow the existing natural balanced-cropping system, then this may pressure the local government to implement dike-heightening projects for the rest of the floodplain.

There is evidence that shows that rice farmers are now following a long-term adaptation strategy to mitigate their unstable and highly volatile income by transferring the younger generation to non-rice production. This situation questions the future of rice production in VMD (in general) considering that the current average age of rice farmers is more than 40 years old. Although the following recommendation is beyond the scope of this study, future policies and policy reforms should focus more on increasing farmers' income and the share of farmers' income in the rice value chains. As found in the study of Tran, Do, and Le (2013), farmers receive much lesser benefits than the other players in the rice value chain who are not directly involved in the production process.

Mekong Delta's fishery is crucial to the livelihoods of the people living in VMD, rich or poor. The bulk of the catch is harvested by part-time and subsistence fishers who are poor and who generally use fishing as part of a diversified livelihood strategy. Hence, fishers are disadvantaged by dike heightening. This can escalate socioeconomic tensions due to the increase in poverty and reduction in community self-sufficiency. The government should therefore focus more on protecting the existing wild fish supply, such as supporting rice-fish integration, which is the most successful system to help mitigate the pressure on wild fish (Le 2008).

Lastly, the government should reconsider the strategy of rice intensification in VMD for the purpose of increasing rice output to achieve rapid economic development based on rice export. Instead, the government should incorporate greater appreciation of the Mekong Delta as an environmental system that provides multiple ecosystem services. The Vietnamese government could consider other "soft" approaches, such as supporting improved quality and the Vietnamese rice brand so that Vietnamese farmers' rice output can command better prices in the market (Tran, Do, and Le 2013).

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Appendix 1. Calculation of pesticide-use external cost (TEC)

STEP 1: In order to calculate EC_c, redistribute the external cost estimates [as calculated by Pretty et al. (2000)] among the categories in the EIQ model developed by Kovach et al. (1992). EC_c is the external cost base values distributed among the EIQ categories.

1. *Convert the external cost (EC) as estimated by Pretty et al. (2000), and then convert the resulting values into 2012 VND values.*

The PEA model uses the mean value of the three countries from each category to provide a single baseline external cost for 1 kg of active ingredient of an average pesticide.

Table 1. Conversion of the external costs to 2012 VND values

Categories in Pretty et al. (2000)	Mean cost per kg a.i. (EUR at 2005 rates) EC	Mean cost per kg a.i (VND at 2012 prices) EC
1. Contamination of drinking water	5.6	238,249.57
2. Pollution incidents, fish death, monitoring	0.81	34,461.10
3. Biodiversity/wildlife losses	0.52	22,123.17
4. Cultural, landscape, tourism, etc.	1.33	56,584.27
5. Bee colony losses	0.13	5,530.79
6. Acute effects to human health	0.39	16,592.38
7. Total external costs	8.78	373,541.29

Source:Leach and Mumford (2008)

Notes: (1) EC = external costs as estimated by Pretty et al. (2000), which were then converted to 2012 VND values (temporary results) using the consumer price index of Vietnam; (2) Average 2005 exchange rate: 19.692VND/EURO (http://www.ozforex.com.au/forex-tools/historical-rate-). Consumer price index 2012: 216.05% (The World Bank Data, 2013). Hence, total external costs = 8.78 x 216.05/100 x 19.692 = 373,541.29 VND

2. *Input the average per kilogram active ingredient external cost categories (Table 1) into the EIQ system (Kovach et al. 1992) categories.*

The PEA model transposes the average per kilogram active ingredient external cost categories and apportions these six categories into eight specific components used in the EIQ system. EC_c will be calculated based on Table 1 and Table 2.

Table 2. Ratio distribution to integrate the external costs of pesticide use and EIQ

Categories in Pretty et al. (2000)	EIQ categories							
	Applicators (1)	Pickers (2)	Consumers (3)	Groundwater (4)	Aquatic Effects (5)	Birds (6)	Bees (7)	Beneficial Insects (8)
1. Contamination of drinking water	0.1	0.1	0.6	0.1	0.1			
2. Pollution incidents, fish death, monitoring				0.5	0.5			
3. Biodiversity/wildlife losses					0.3	0.3	0.1	0.3
4. Cultural, landscape, tourism, etc.			0.5			0.2	0.1	0.2
5. Bee colony losses							1.0	
6. Acute effects to human health	0.8	0.15	0.05					

Source: Leach and Mumford (2008)

Note: These ratios are not definitive, and the PEA model allows the user to change and reflect how the two systems should be integrated for specific situations. Thus, these ratios may be adjusted to better represent the Vietnam case and may need the local expert's advice on the adjustments (hydrologists, environmentalists, etc.). However, there is no clear definition that would enable the researcher to establish ratios. Thus, it is not clear how this can be adjusted or whether it could be adjusted.

Table 3. Distribution of external costs [based on Pretty et al. (2001)] categories to the EIQ system for 1 kg of active ingredient for the average pesticide (in VND/kg)

Categories in Pretty et al. (2000)	EIQ categories							
	Applicators	Pickers	Consumers	Ground Water	Aquatic Effects	Birds	Bees	Beneficial Insects
1. Contamination of drinking water	23,824.96	23,824.96	142,949.74	23,824.96	23,824.96			
2. Pollution incidents, fish death, monitoring				17,230.55	17,230.55			
3. Biodiversity/wildlife losses					6,636.95	6,636.95	2,212.32	6,636.95
4. Cultural, landscape, tourism, etc.			28,292.14			11,316.85	5,658.43	11,316.85
5. Bee colony losses							5,530.79	
6. Acute effects to human health	13,273.90	2,488.86	829.62					
EC_c	37,098.86	26,313.82	172,071.50	41,055.51	47,692.46	17,953.80	13,401.54	17,953.80

STEP 2: To calculate the external costs of pesticide use for each pesticide, collect the needed data on farmers' average application rate [(A_p*p_active_p), (kg a.i./ha)] from the field survey

A_p = application rate (kg/ha) of pesticide *p* for a total of *m* pesticides [will be obtained from field survey (rice-producing households)]

p_active_p = proportion of active ingredients in the formulated product [will be obtained from field survey (pesticide traders, pesticide shops, and pesticide producers)]

STEP 3: For each EIQ category, calculate F_c by determining if a pesticide is of relatively low, medium, or high toxicity. F_c takes on three values: 0.5 = chemical has a relatively low level of toxicity; 1.0 = medium toxicity; 1.5 = highly toxic.

1. *Get $EIQ_{p,m}$ for all pesticides from the Cornel University web.*

Table 4. Example of $EIQ_{p,m}$ for one pesticide

Pesticide (example)	$EIQ_{p,m}$ over EIQ categories							
	Applicators	Pickers	Consumers	Ground-water	Aquatic Effects	Birds	Bees	Beneficial Insects
Methomyl	5	1	6	5	3	6	15	25

Source: Cornel University (2012)

Note: $EIQ_{p,m}$ = base value of the active ingredients over eight categories of EIQ

2. *Calculate F_c for all pesticides.* F_c will be calculated based on $EIQ_{p,m}$ (Table 5) and on the quotient classification for each EIQ category (Table 6).

Table 5. Quotient classification for each EIQ category

Range of EIQ Values	*Fc*	EIQ categories							
		Applicators	Pickers	Consumers	Ground-water	Aquatic Effects	Birds	Bees	Beneficial Insects
Low	0.5	< 25	< 14	< 16	< 2	< 5	< 15	< 15	< 25
Medium	1.0	25–85	14–76	16–55	2–4	5–17	15–51	15–51	25–85
High	1.5	> 85	> 76	> 55	> 4	>17	> 51	> 51	> 85

Source: Leach and Mumford (2008)

Table 6. Example of F_c for one pesticide

Pesticide (example)	F_c over EIQ categories							
	Applicators	Pickers	Consumers	Ground-water	Aquatic Effects	Birds	Bees	Beneficial Insects
Methomyl	0.5	0.5	0.5	1.5	0.5	0.5	1.0	1.0

STEP 4: Calculate the economic adjustment factors.

F_{agemp} is a ratio of Mekong Delta's share of employment in agriculture to the average share of agricultural employment in Germany, UK, and US (weighted by GDP). The author chose the share of agricultural labor in total employment, as it better reflects the number of people likely to come into direct contact with pesticides on farms (Praneetvatakul et al. 2013) instead of following Leach and Mumford (2008), which used the share of agricultural sector in the GDP as a proxy for health-related externalities. Therefore, the author multiplied the external costs for farm workers (c = 1, 2) by F_{agemp}.

The Vietnam's share of agricultural employment in 2011 was 48.4% (2012 figure was not available). The average share of agricultural employment in Germany, UK, and US (weighted by GDP) was 1.42% (Praneetvatakul et al. 2013).

F_{gdpc} is a ratio of Vietnam's per capita GDP to average per capita GDP in Germany, UK, and US (weighted by GDP). In 2012, the Vietnam's per capita GDP in USD was USD 3,635.21, and the weighted average per capita GDP for Germany, UK, and US was USD 46,968.78 (WB 2013a).

F_{agemp}, F_{gdppc} adjustment factors will be calculated using data from World Bank database.

Table 7. Calculate the economic adjustment factors

Adjustment Factor	EIQ categories							
	Applicators	Pickers	Consumers	Ground-water	Aquatic Effects	Birds	Bees	Beneficial Insects
F_{agemp}	34.09	34.09	1.00	1.00	1.00	1.00	1.00	1.00
F_{gdppc}	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

Appendix 2. Pesticide questionnaire

1. Summer-Autumn season

Types of Pesticide (Trade Name)	Science Name	Active ingredient (%)	Number of Application (times)	Applied Quantity per Time (bottle size, ml)			Unit Price (VND/bottle)			Total Amount (ml/ha)	Total Cost (VND)
				Small	Med	Big	Small	Med	Big		
1. Insecticides											
–											
–											
Labor cost											
Family cost											
Fungicides											
–											
–											
Labor cost											
Family cost											
Acaricides											
–											
Labor cost											
Family cost											
Herbicides											
–											
–											
Labor cost											
Family cost											
Other/unknown											
–											
–											
Labor cost											
Family cost											

Appendix 3. Rice production questionnaire

The date of interview: ____________________________
Interviewer: ____________________________________

I. PERSONAL INFORMATION OF HOUSEHOLDER

1. The name of householder: _________________________________
2. Address: ____
3. Tel: ____
4. The gender of interviewee: *1. Male 2. Female*
5. The education of interviewee: grade_________________________
6. The date of birth: _____________year.
7. Number of members in the family: ________persons. *Including:*
   Male: ________The number of males who are more 16 years old: ________
   Female: ______The number of females who are more 16 years old: ________
8. Do you take part in any rice trainings? *1. Yes 2. No*
   If "Yes", the number of trainings per year: ________What is the period of a training? ________day(s)
   Total days of trainings: ________day(s).
   The subject(s) and organizer(s) of the trainings:

(i) ____
(ii) ____
(iii) ____

9. Do you take part in any rice workshops? *1. Yes 2. No*
   If "Yes", the number of workshops per year: ________workshop(s)
   The subject(s) (etc. fertilizer, pesticide) and organizer(s) of the workshops:

(i) ____
(ii) ____
(iii) ____

II. INFORMATION ABOUT FARMER

1. Total cultivation area: ________ (ha); *1. In surrounding dike 2. Semi-dike*
2. When was the dike built? Year________
3. Number of rice crops per year: ________rice land ________ha
   Rice growing area: Winter-Spring: ________ (ha)
   Summer-Autumn: ________ (ha)
   Autumn-Winter: ________ (ha)
4. When did you begin to grow two rice crops? Year ________
5. When did you begin to grow three rice crops? Year ________
6. Why did you choose to grow two crops?
   1. More income
   2. No high dike available
   3. Supported technologies and finances
   4. Supported by companies
   5. Available experience
   6. Following Governmental policies
   7. The high productivity
   8. Others: ________

7. Why did you choose to grow three crops?
    1. More income *5. Available experience*
    2. High dike, preventing loss due to flood *6. Following Governmental policies*
    3. Supported technologies and finances *7. The high productivity*
    4. Supported by companies *8. Others: ________*

8. Is the rice area irrigated and drained by cooperatives? *1. Yes 2. No*
    Pump yourself : *1. Yes 2. No*

9. Is your land fertile?
    1. Vey fertile 2. Fertile 3. Medium 4. Not fertile 5.Very not fertile

10. How far is the rice farm area from your house? ________km

11. Have you ever applied IPM before? *1. Yes 2. No*

12. What have you applied in detail (etc. don't apply pesticide in the first 40 days after seeding, visit field regularly to control enemies/pests density)?

13. Do you have to apply more pesticide per crop for the three-crop system as compared to the two-crop system per year? *1. Yes 2. No*

14. If yes, how much do you apply?
    1. Very high 2. High 3. Medium 4. Low 5. Very low

15. What are the main kinds of pest (etc. herb, insects, bacteria, fungi) that have usually occurred for five years

16. For the last five years, were there any disasters that affected your rice production? *1. Yes 2. No*

17. If yes, please give the name of disasters: ________________________

18. For the last five years, were there any epidemics (etc. rầynâu, lùnxoắnlá) that affected your rice production? *1. Yes 2. No*

19. If yes, please give the name of epidemics:

20. As compared to five years ago, has your rice profit decreased or not?
    1. Decreased 2. The same 3. Increased

21. According to you, why did it increase/decrease?

22. As compared to five years ago, has standard of living improved?
    1. Improved 2. The same 3. Decreased

23. Why did your standard of living worsened?

	Main reasons	Extra-reason
- Decrease in yield:	(1)	(1)
- Ill people:	(2)	(2)
- Borrowing with high interest:	(3)	(3)
- Selling products with low price	(4)	(4)
- Buying inputs with high price:	(5)	(5)

24. Where do you borrow money for rice cultivation?
1. From formal financial organizations *2. From informal sources*

II. RICE PRODUCTION

1. Summer-Autumn season

1.1 The period : _________months
1.2 Total cost: _________’000 VND
1.3 Name of variety: _________
1. Commercial seed *2. Certificated seed*
1.4 Source of seed:
____.
____
1.5 Rice production

Unit: 1,000VND

Item	Amount	Unit Price	Total Cost	Notes
1. Land preparation				
Services (ha)				
Hired labor (days)				
Family labor (days)				
2. Seeding				
Growth duration (days)				
Seed amount				
Seeding cost				
Family labor (days)				
3. Fertilizer				
Fertilizer amount (kg/ha)				
– NPK				
– Urea				
– Phosphate				
– Kali				
– DAP				
– Foliar fertilizer				
– Organic fertilizer				
Hired labor (days)				
Family labor (days)				
4. Irrigation				
Irrigation cost				
Service cost				
Rebuilt dike				
Fuel (doing by self) (days)				
Family labor (days)				
5. Harvest				
Service cost (by harvester)				
Transportation cost				
Hired labor (days)				
Family labor (days)				
Others: _________				
6. Processing and Selling				
Drying cost				
Hired labor (days)				
Family labor (days)				
7. Other cost				

1.6 Total family labors: _________________days.

1.7 Income: _________________ '000 VND per total area

Yield (t/ha)	Amount (t)	Sale Amount (t)	Min Price ('000 VND/t)	Max Price ('000 VND/t)	Current Price ('000 VND/t)

2. Autumn-Spring season

2.1 The period : _________months

2.2 Total cost: _________ '000 VND

2.3 Name of variety: _________

1. Commercial seed *2. Certificated seed*

2.4 Source of seed:

____.

____

2.5 Rice Production

Unit: '000 VND

Item	Amount	Unit Price	Total Cost	Notes
1. Land preparation				
Services (ha)				
Hired labor (days)				
Family labor (days)				
2. Seeding				
Growth duration (days)				
Seed amount				
Seeding cost				
Family labor (days)				
3. Fertilizer				
Fertilizer amount (kg/ha)				
– NPK				
– Urea				
– Phosphate				
– Kali				
– DAP				
– Foliar fertilizer				
– Organic fertilizer				
Hired labor (days)				
Family labor (days)				
4. Irrigation				
Irrigation cost				
Service cost				
Rebuilt dike				
Fuel (doing by self) (days)				
Family labor (days)				
5. Harvest				
Service cost (by harvester)				
Transportation cost				
Hired labor (days)				
Family labor (days)				
Others: _________				
6. Processing and Selling				
Drying cost				
Hired labor (days)				
Family labor (days)				
7. Other cost				

2.6 Total family labors: _________________ days.

2.7 Income: _________________ 1,000 VND per total area

Yield (t/ha)	Amount (t)	Sale Amount (t)	Min Price ('000 VND/t)	Max Price ('000 VND/t)	Current Price ('000 VND/t)

3. Spring-winter season

3.1 The period: _________months

3.2 Total cost: _________ '000 VND

3.3 Name of variety: _________

1. Commercial seed   2. Certificated seed

3.4 Source of seed:

____.

____

3.5 Rice production

Unit: '000 VND

Item	Amount	Unit Price	Total Cost	Notes
1. Land preparation				
Services (ha)				
Hired labor (days)				
Family labor (days)				
2. Seeding				
Growth duration (days)				
Seed amount				
Seeding cost				
Family labor (days)				
3. Fertilizer				
Fertilizer amount (kg/ha)				
– NPK				
– Urea				
– Phosphate				
– Kali				
– DAP				
– Foliar fertilizer				
– Organic fertilizer				
Hired labor (days)				
Family labor (days)				
4. Irrigation				
Irrigation cost				
Service cost				
Rebuilt dike				
Fuel (doing by self) (days)				
Family labor (days)				
5. Harvest				
Service cost (by harvester)				
Transportation cost				
Hired labor (days)				
Family labor (days)				
Others: _________				
6. Processing and Selling				
Drying cost				
Hired labor (days)				

Item	Amount	Unit Price	Total Cost	Notes
Family labor (days)				
7. Other cost				

3.6 Total family labors: _________________days.

3.7 Income: _________________ ‘000 VND per total area

Yield (t/ha)	Amount (t)	Sale Amount (t)	Min Price (‘000 VND/t)	Max Price (‘000 VND/t)	Current Price (‘000 VND/t)

Appendix 4. Characteristics of rice varieties in high-dike and low-dike areas

Table 1. Characteristics of rice varieties in high-dike and low-dike areas

Category	High-Dike Area	Low-Dike Area
Main varieties (name)	IR 50404 OM 6976	Jasmine 85 OM 4218
Farmers using (%)	74–77	80–94
Features of main varieties	average to high resistance to main insects and diseases	infected to heavy infected by the main insects and diseases
Seed price (‘000 VND/kg)		
Mean	9.53[a]	13.01[b]
SD	4.29	1.67
Output price (‘000 VND/t)		
Mean	4,406[a]	5,319[b]
SD	526.88	557,99

Notes: (1) Means that do not share the same superscript letter are significantly different using t-test ($P < 0.05$); (2) Using Wilconxon rank-sum test for comparing medians shows the same results; (3) Seed and output prices are the averages of all of the farmers’ output from the first two crops, excluding the third crop. This is in order for the output to be comparable between the two cropping systems.

Appendix 5. Impacts of water management on golden apple snails in high-dike and low-dike areas

The water management process and the interaction that goes on between in the two areas is described in detail to show that abundant of golden apple snails is diverted from high-dike areas to low-dike areas during winter-spring crop (third crop).

During summer-autumn crop. Rice farmers in both areas utilize the same water management—pumping water (with golden apple snails) from the canal to the rice fields or back to the canal.

In the early period of summer-autumn rice crop. At the beginning of the rainy season, the farmers in the low-dike and high-dike areas pump water from the canal into their fields as rainfall is not enough for rice cultivation. Through water pumping, golden apple snails are transferred to and subsequently develop in both areas.

In the late period of summer-autumn rice crop. Together with the early flooding that *occurs* annually during the last days of the summer-autumn rice crop, the heavy rains threaten the second rice crops in both the high-dike and low-dike areas. Farmers then have to pump water out of their fields during harvest period. Through water pumping, golden apple snails are transported back to the canal.

During autumn-winter crop. At this stage, the water management of the two rice production models is different from each other. In the high-dike areas, intensive crop farmers continuously pump water (as well as golden apple snails and their eggs) out of their fields to the overflowing canals and low dike-areas in order to maintain their third rice crop. Consequently, the golden apple snails develop in the over-flooded low-dike areas, while the third rice crop is grown in the high-dike areas during the rainy season (Figure 1).

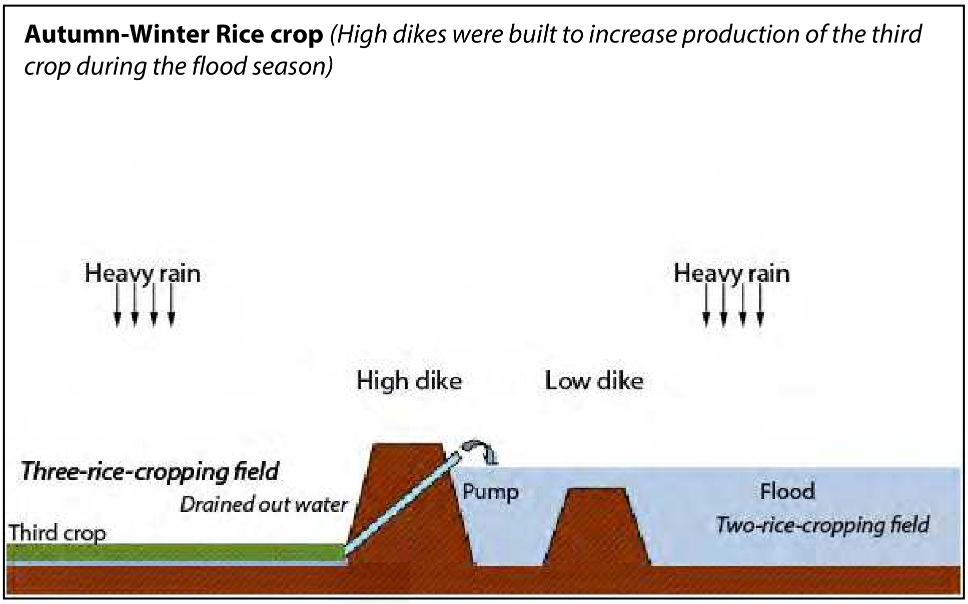

Figure 1. Water management during autumn-winter rice crop (rainy season)

During winter-spring crop. Rice farmers in both areas utilize the same water management: pumping water (with golden apple snails) from the rice fields to the canal. At the end of autumn-winter crop period, the volume of rainfall decreases; however, floodwater still remains in both rice-production areas. Farmers have to pump the water out of the field into the canal in order to start sowing their first rice crop of the year (the winter-spring rice crop).

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